PB90-171919

PATHOGEN RISK ASSESSMENT FOR LAND APPLICATION OF MUNICIPAL SLUDGE. VOLUME II: USER'S MANUAL

(U.S.) Environmental Protection Agency
Cincinnati, OH

Nov 89

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/6-90/002 B	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Pathogen Risk Assessment for Land Application of Municipal Sludge Volume I: Methodology and Computer Model Volume II: User's Manual		5. REPORT DATE November 1989
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Criteria and Assessment Office Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE EPA/600/22

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Section 405 of the Clean Water Act requires the U.S. EPA to develop and issue regulations that identify: 1) uses for sludge including disposal; 2) specific factors (including costs) to be taken into account in determining the measures and practices applicable for each use or disposal; and 3) concentrations of pollutants that interfere with each use or disposal. To comply with this mandate, the U.S. EPA has embarked on a program to develop four major technical regulations: land application, including distribution and marketing; landfilling; incineration and surface disposal. The develop of these technical regulations requires a consideration of pathogens as well as chemical constituents of sludge. The purpose of this report is to describe a proposed methodology and associated computer model designed to assess the potential risks to human health posed by pathogens in municipal sewage sludge applied to land as fertilizer or soil conditioner. Volume I: Methodology and Computer Model describes the conceptual framework of the risk assessment methodology and the structural organization, including assumptions and components, of the computer model. Volume II: User's Manual contains background information to provide the user with an understanding of the actual functioning of the model. This information includes descriptions of operating variables and their default values, explanations of the various subroutines, and the mathematical basis for process and transfer functions.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 281
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

PB90-171919

EPA/600/6-90/002B
November 1989

PATHOGEN RISK ASSESSMENT FOR LAND APPLICATION OF MUNICIPAL SLUDGE
VOLUME II: USER'S MANUAL

Environmental Criteria and Assessment Office
Office of Health and Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

DISCLAIMER

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

Section 405 of the Clean Water Act requires the U.S. Environmental Protection Agency to develop and issue regulations that identify: (1) uses for sludge including disposal; (2) specific factors (including costs) to be taken into account in determining the measures and practices applicable for each use or disposal; and (3) concentrations of pollutants that interfere with each use or disposal. To comply with this mandate, the U.S. EPA has embarked on a program to develop four major technical regulations: land application, including distribution and marketing; landfilling; incineration and surface disposal. The development of these technical regulations requires a consideration of pathogens as well as chemical constituents of sludge. Public concern related to the reuse and disposal of municipal sludge often focuses on the issue of pathogenic organisms. The purpose of this report is to describe a proposed methodology and associated computer model designed to assess the potential risks to human health posed by pathogens in municipal sewage sludge applied to land as fertilizer or soil conditioner.

Volume I: Methodology and Computer Model describes the conceptual framework of the risk assessment methodology and the structural organization, including assumptions and components, of the computer model. Volume II: User's Manual contains background information to provide the user with an understanding of the actual functioning of the model. This information includes descriptions of operating variables and their default values, explanations of the various subroutines, and the mathematical basis for process and transfer functions.

The first draft of this document was prepared by Science Applications International Corporation under a U.S. EPA Interagency Agreement with the Department of Energy. Portions of the document were also developed by the University of Cincinnati under a Cooperative Agreement with the U.S. EPA.

DOCUMENT DEVELOPMENT

Cynthia Sonich-Mullin, Project Officer
Norman E. Kowal
Randall J.F. Bruins
Larry Fradkin
Environmental Criteria and Assessment Office
U.S. Environmental Protection Agency
Cincinnati, Ohio

Marialice Wilson, Project Manager
Science Applications International Corporation
Oak Ridge, TN

Charles T. Hadden
Analysas Corporation
Oak Ridge, TN

Mary P. Stevenson, Model Revision
Jennifer Webb Chason, Model Revision
Ernie L. Burress, Model Revision
Science Applications International Corporation
Oak Ridge, TN

Milovan S. Beljin, Sensitivity Analysis
Groundwater Research Center
The University of Cincinnati
Cincinnati, OH

Contributors

Rafael Livneh
Steven G. Buchberger
T. Michael Baseheart
Pasquale Scarpino
Scott Clark
The University of Cincinnati
Cincinnati, OH

Charles A. Sorber
University of Pittsburgh
Pittsburgh, PA

Charles P. Gerba
University of Arizona
Tucson, AZ

Richard Ward
The Christ Hospital
Cincinnati, OH

TABLE OF CONTENTS

Page

1. EXECUTIVE SUMMARY 1-1

2. STRUCTURE OF THE MODEL 2-1

  2.1. MODEL OVERVIEW 2-1
  2.2. STRUCTURE OF THE COMPUTER PROGRAM 2-7
  2.3. COMPILING AND LINKING 2-10

3. OPERATING VARIABLES AND THEIR DEFAULT VALUES 3-1

  3.1. VARIABLES FOR PROGRAM MODEL 3-1
  3.2. VARIABLES AND DEFAULT VALUES FOR SUBROUTINE RISK 3-13

    3.2.1. Subroutine VEG 3-13
    3.2.2. Subroutine MEAT. 3-17
    3.2.3. Subroutine MILK. 3-19

  3.3. VARIABLES AND DEFAULT VALUES FOR SUBROUTINE RAINS 3-21
  3.4. VARIABLES AND DEFAULT VALUES FOR SUBROUTINE GRDWTR 3-23

4. OPERATION OF THE MODEL 4-1

  4.1. COMPARTMENT DIFFERENTIAL EQUATIONS 4-1
  4.2. TRANSFER FACTORS 4-3
  4.3. TRANSFER TIMES 4-12
  4.4. PROCESS FUNCTIONS 4-21

5. COMPLEX TRANSFER FUNCTIONS 5-1

  5.1. PARTICULATE EMISSIONS FOLLOWING APPLICATION/INCORPORATION 5-1

    5.1.1. Tilling Emissions 5-1
    5.1.2. Wind Erosion. 5-2
    5.1.3. Onsite Exposures. 5-4
    5.1.4. Offsite Exposures. 5-6

  5.2. LIQUID DROPLET AEROSOLS 5-10
  5.3. SURFACE RUNOFF AND SEDIMENT TRANSPORT 5-11
  5.4. GROUNDWATER AT AN OFFSITE WELL 5-12

6. SAMPLE INPUT AND OUTPUT 6-1

  6.1. INPUT. 6-1
  6.2. INFECTION PROBABILITIES 6-15

TABLE OF CONTENTS (continued)

6.3. CONTENTS OF COMPARTMENTS 6-16
6.4. SURFACE RUNOFF AND SEDIMENT TRANSPORT 6-24
6.5. SUBSURFACE TRANSPORT 6-31

7. REFERENCES 7-1

APPENDIX A. VARIABLES AND DEFAULT VALUES A-1

APPENDIX B. SURFACE RUNOFF AND SEDIMENT LOSS B-1

LIST OF TABLES

No.	Title	Page
A-1	Position Number, Name, Default Values, and Definition of Input Variables	A-2
A-2	Pathogen-Specific Default Values	A-5
A-3	Proposed Initial Value Menu for Pathogen Concentration Parameter, ASCRS	A-7
A-4	Variables and Default Values for Subroutine RISK	A-8
A-5	Variables and Default Values for Subroutine RAINS	A-11
A-6	Variables and Default Values for Subroutine GRDWTR	A-12
A-7	Transfer Factors and Functions for Practices I - V	A-13
A-8	Transfer Times for Practices I - V	A-16
A-9	Average Monthly Temperatures at Several Reporting Stations, Continental United States	A-19
A-10	Constants for Temperature Dependence of Process Functions for Bacteria in Soil	A-20
A-11	Optional Variables for Growth or Inactivation Rate	A-21
A-12	Process Functions for Practices I - V	A-22

LIST OF FIGURES

No.	Title	Page
2-1	Input/Output Diagram for Practice I--Application of Liquid Sludge for Production of Commercial Crops for Human Consumption	2-2
2-2	Input/Output Diagram for Practice II--Application of Liquid Sludge to Grazed Pastures	2-3
2-3	Input/Output Diagram for Practice III--Application of Liquid Sludge for Production of Crops Processed before Animal Consumption	2-4
2-4	Input/Output Diagram for Practice IV--Application of Dried or Composted Sludge to Residential Vegetable Gardens	2-5
2-5	Input/Output Diagram for Practice V--Application of Dried or Composted Sludge to Residential Lawns	2-6
4-1	Temperature Variation Fit to Sine Function	4-22
4-2	Process Function (RHO), Die-off of Salmonella in Moist Soil	4-24
5-1	Wind Erosion Function	5-5
5-2	Air Diffusion Model Offsite Transport	5-9
5-3	Subroutine RAINS Output	5-13
5-4	Effect of Distance on Contents of Water Well	5-15
5-5	Effect of Groundwater Velocity on Contents of Water Well	5-16
5-6	Effect of Hydrodynamic Dispersion Coefficient on Contents of Water Well	5-17

1. EXECUTIVE SUMMARY

Volume II: User's Manual is the companion volume to Volume I: Methodology and Computer Model, both of which comprise Pathogen Risk Assessment for Land Application of Municipal Sludge. Volume II describes the structure and functioning of the computer model and provides a sample run of the program.

The five municipal sewage sludge management practices addressed by the model are: application of liquid treated sludge (1) for production of commercial crops for human consumption, (2) to grazed pastures, and (3) for production of crops processed before animal consumption; and application of dried or composted sludge (4) to residential vegetable gardens and (5) to residential lawns. Each of these five practices is characterized as a series of compartments in which the number of one of the three pathogen types--Salmonella, Ascaris or enterovirus--can increase, decrease or remain the same (process functions). The movement of pathogens between compartments is described by transfer functions.

The objective of the model is to determine the probability of infection of a human receptor by pathogens in the land-applied sludge. The user of the model has the option of modifying many of the operating variables used by the program to calculate the number of organisms present in the compartments. These variables include initial pathogen concentration; organism type; environmental parameters such as soil temperature and moisture, air temperature, windspeed, rainfall amount and frequency; and parameters descriptive of the land application practice modeled such as size of field or garden, type of crop, irrigation method and frequency, timing and yield of harvest or size of cattle herd. There are also variables for the subroutines that represent rainfall, groundwater and crop preparation practices. Operation of the model is governed by a series of compartment differential equations, transfer factors and times, and process functions. These equations calculate the increase or decrease of pathogens within each compartment and the transfer of pathogens from one compartment to another at intervals during the model run. Transfers may be conditional on a particular applications option such as spray irrigation, on time after initiation of the practice or on physical processes such as rainfall or dust storms. The more complex transfer functions are those resulting from generation of particulate emissions by wind erosion or tilling, from generation of liquid aerosols during spray irrigation using wastewater, from transport of soil-bound microorganisms by surface runoff associated with rainfall or from subsurface transport of pathogens associated with groundwater movement.

Preliminary conclusions drawn from sample runs of the model suggest that the most likely candidate for infection is an onsite human receptor who ingests pathogens from direct contact or from contaminated surface runoff confined onsite; the probability of infection of an offsite human receptor seems relatively low if surface runoff does not move offsite.

2. STRUCTURE OF THE MODEL

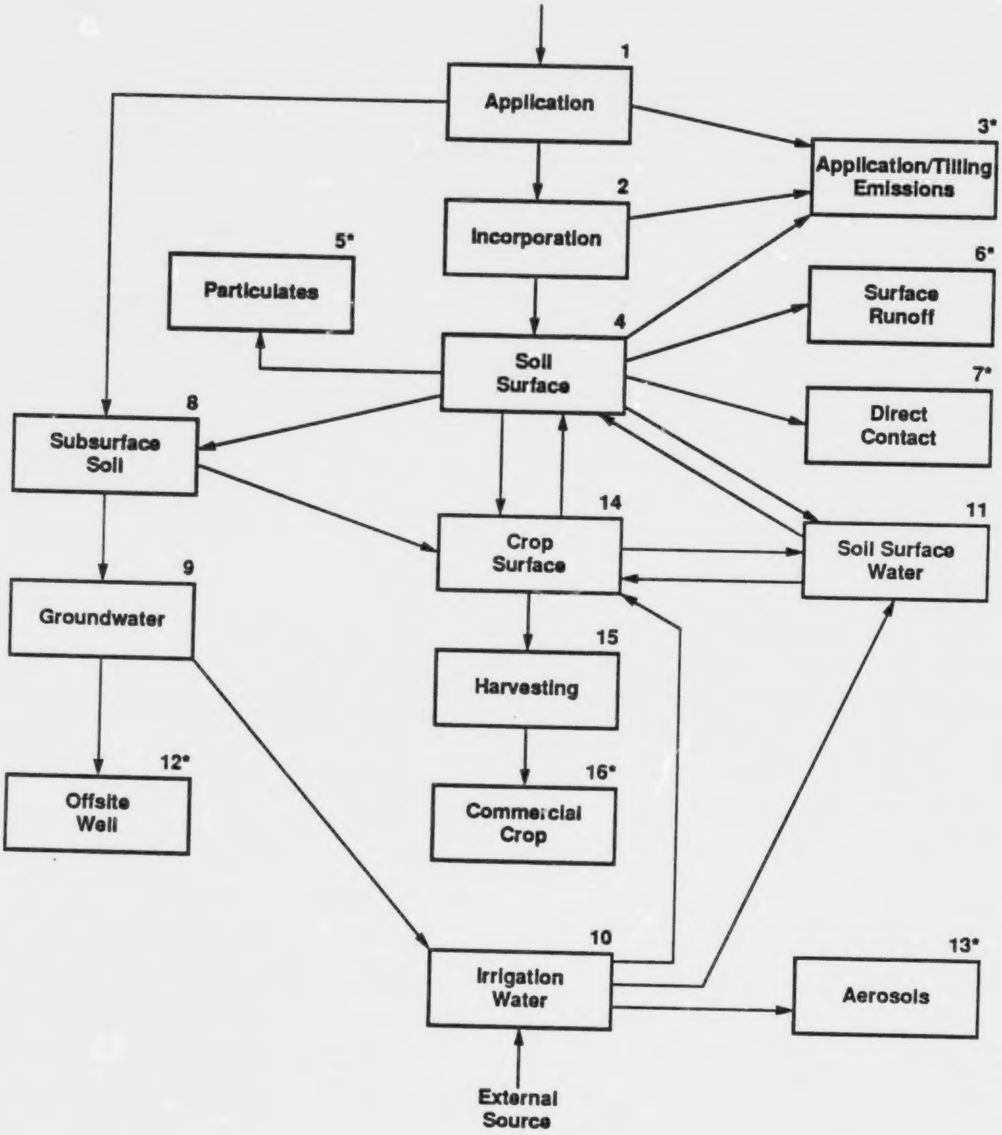
2.1. MODEL OVERVIEW

The five application practices comprising the model are described in detail in the accompanying document, Pathogen Risk Assessment for Land Application of Municipal Sludge; Volume I, Methodology and Computer Model. Input-output diagrams summarizing the pathways of each practice are reprinted from that document in Figures 2-1 through 2-5. The model is a compartment-vector approach in which a mathematical state represents a discrete point in a treatment or application pathway where pathogen populations are computed as a function of time. Each aspect of the system is modeled as a compartment (n) in which the number of organisms may increase or decrease, as described by a state function. Growth or inactivation is described by a rate parameter (RHOn). Transfer functions (TRxy) describing the movement of organisms into or out of each compartment are denoted by indicating first the number of the compartment from which the transfer is made and then the number of the receptor compartment. Thus a transfer from Compartment 1 to Compartment 2 would be designated TR12.

In each model run a single pathogen type can be specified. The model is designed to calculate the number of organisms in each compartment at 1-hour time increments. Initial and final concentrations of pathogens are calculated for each compartment, using the transfer functions to describe the entry and exit of pathogens. It is assumed that growth or die-off of each organism is exponential with respect to time.

The model includes a set of default values for each rate and initial concentration to be used in the calculations, and the user has the option of substituting other values, corresponding to, for example, different organisms, different treatment conditions or different values of soil temperature, moisture or pH. It contains, therefore, a great deal of built-in flexibility in generating comparative data on pathogen concentrations in various exposure pathways. The endpoint of each release pathway calculation is the number of organisms present in each compartment of the pathway at any given time.

Calculations are done automatically for each compartment of the model option chosen, yielding the predicted concentration of the chosen pathogen in each compartment. Most calculations are done in discrete, 1-hour steps, so most time-related variables are in units of hours. Because discrete, presumably instantaneous events cannot readily be superimposed on continuous exponential functions for growth, inactivation and transfer of pathogens, the exponential functions are converted to linear hourly approximations. Thus an inactivation rate of 1.2 logs per day means that the



1
Application
3*
Application/Tilling Emissions
2
Incorporation
5*
Particulates
6*
Surface Runoff
4
Soil Surface
7*
Direct Contact
8
Subsurface Soil
14
Crop Surface
11
Soil Surface Water
9
Groundwater
15
Harvesting
12*
Offsite Well
16*
Commercial Crop
10
Irrigation Water
13*
Aerosols
External Source

FIGURE 2-1

Input/Output Diagram for Practice I--Application of Liquid Sludge for Production of Commercial Crops for Human Consumption

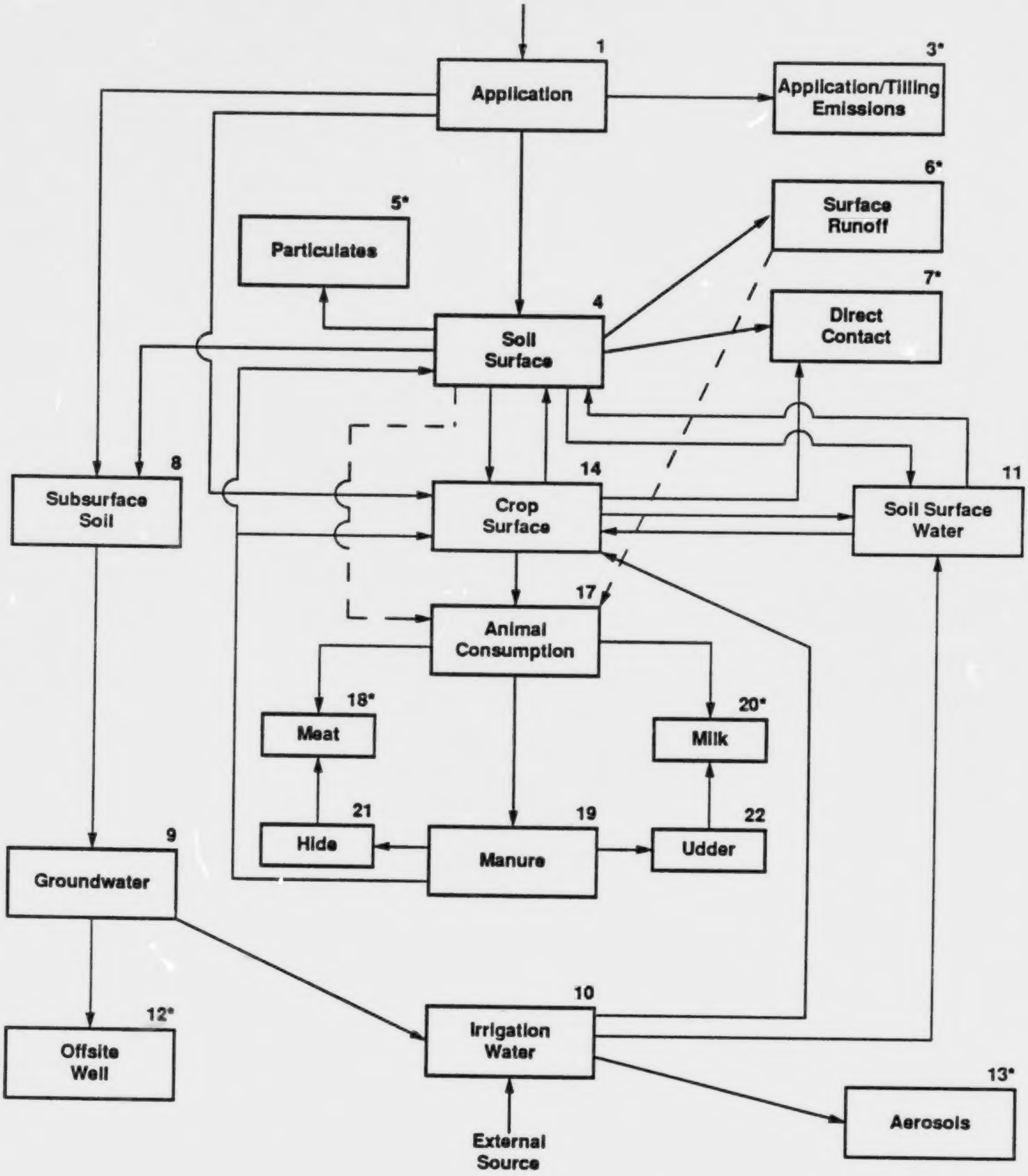

1
Application
3*
Application/Tilling Emissions
6*
Surface Runoff
5*
Particulates
4
Soil Surface
7*
Direct Contact
8
Subsurface Soil
14
Crop Surface
11
Soil Surface Water
17
Animal Consumption
18*
Meat
20*
Milk
21
Hide
19
Manure
22
Udder
9
Groundwater
10
Irrigation Water
12*
Offsite Well
13*
Aerosols
External Source

FIGURE 2-2

Input/Output Diagram for Practice II--Application of Liquid Sludge to Grazed Pastures

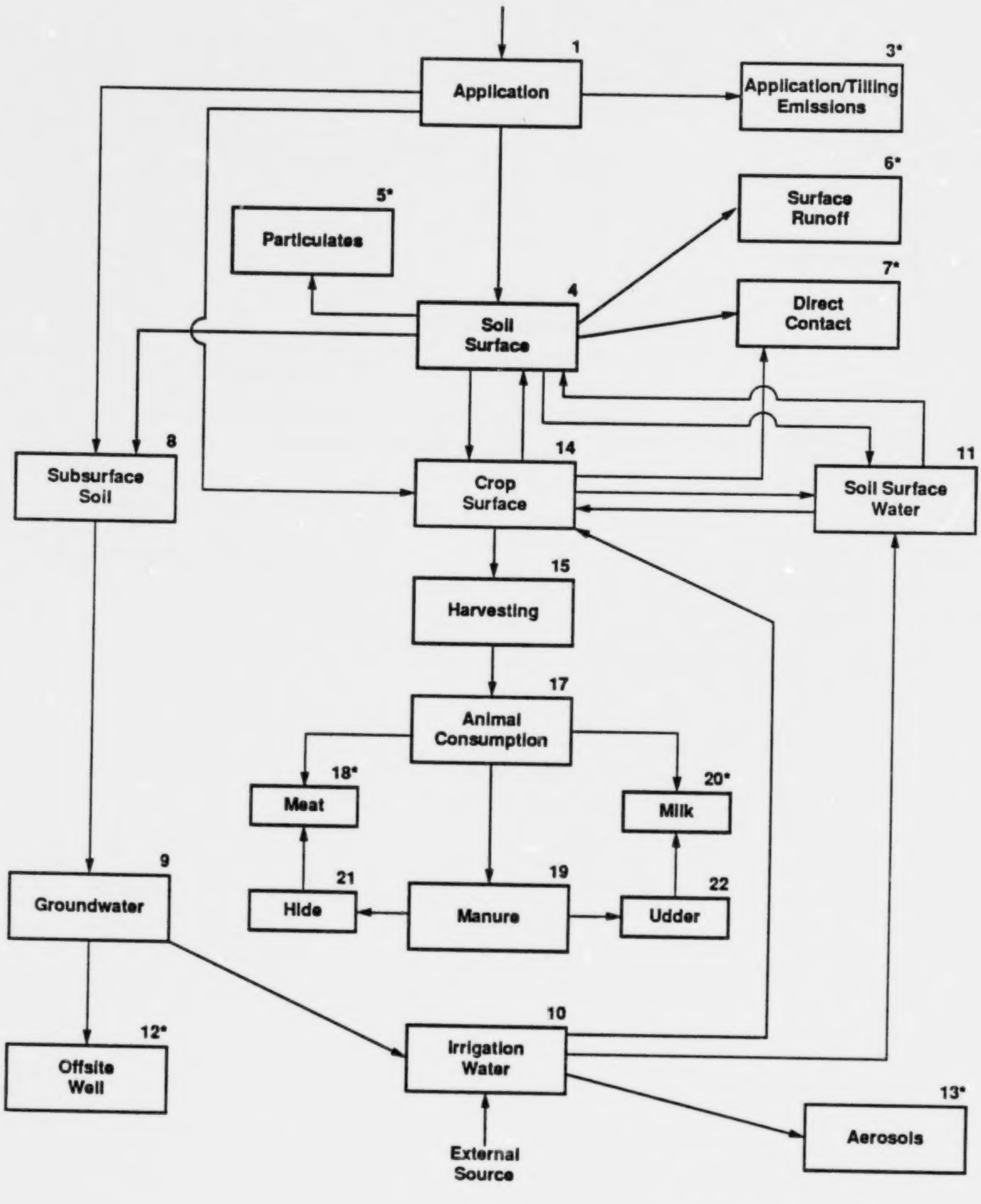

1
Application
3*
Application/Tilling Emissions
6*
Surface Runoff
5*
Particulates
4
Soil Surface
7*
Direct Contact
8
Subsurface Soil
14
Crop Surface
11
Soil Surface Water
15
Harvesting
17
Animal Consumption
18*
Meat
20*
Milk
9
Groundwater
21
Hide
19
Manure
22
Udder
10
Irrigation Water
12*
Offsite Well
13*
Aerosols
External Source

FIGURE 2-3

Input/Output Diagram for Practice III--Application of Liquid Sludge for Production of Crops Processed before Animal Consumption

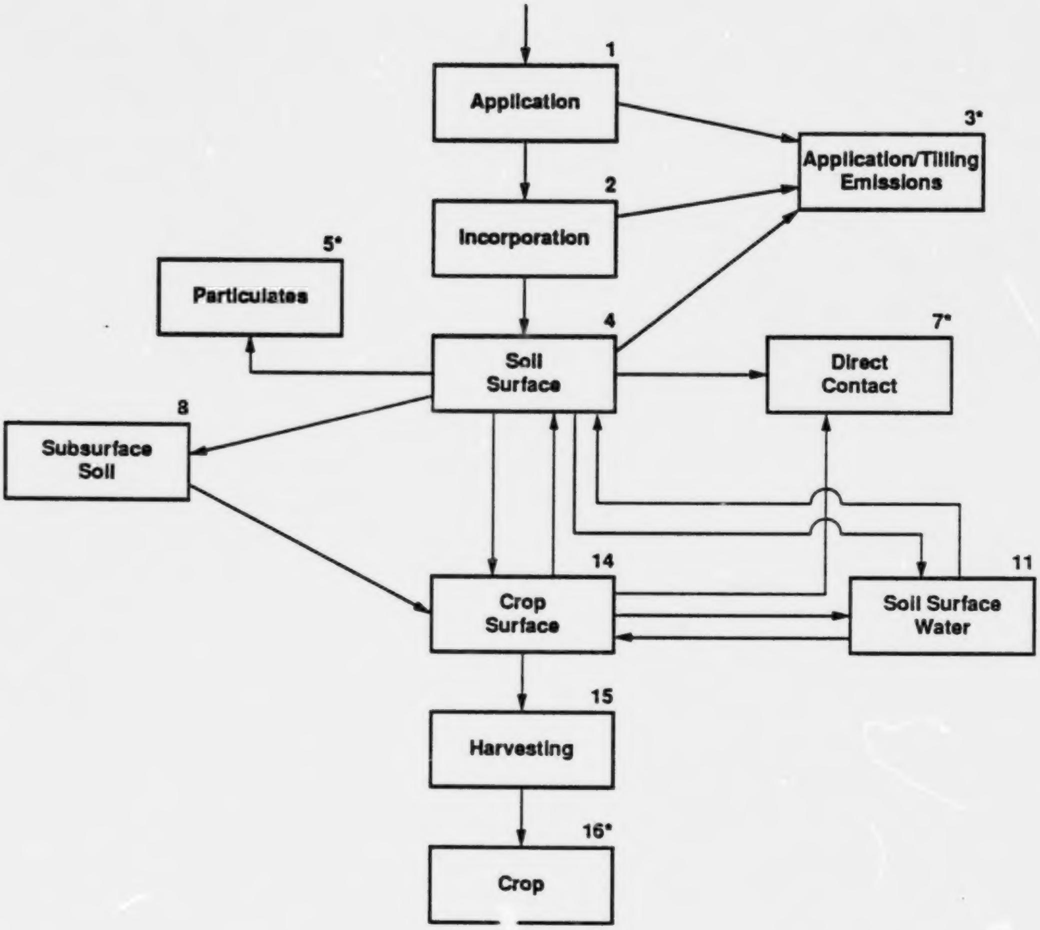
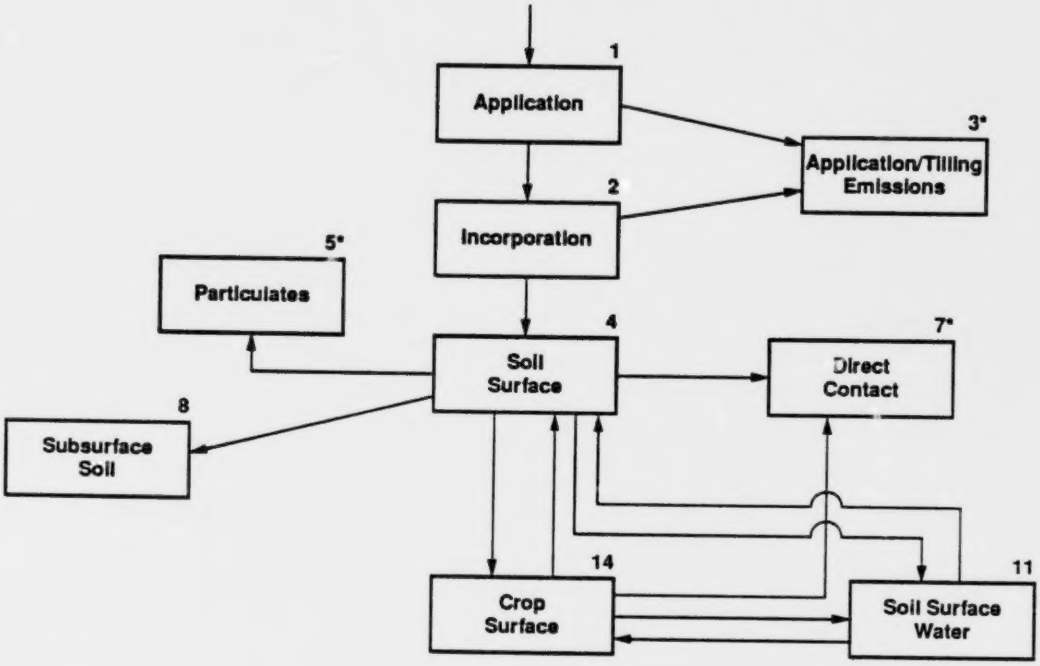

1
Application
3*
Application/Tilling Emissions
2
Incorporation
5*
Particulates
4
Soil Surface
7*
Direct Contact
8
Subsurface Soil
14
Crop Surface
11
Soil Surface Water
15
Harvesting
16*
Crop

FIGURE 2-4

Input/Output Diagram for Practice IV--Application of Dried or Composted Sludge to Residential Vegetable Gardens



1
Application
3*
Application/Tilling Emissions
2
Incorporation
5*
Particulates
4
Soil Surface
7*
Direct Contact
8
Subsurface Soil
14
Crop Surface
11
Soil Surface Water

FIGURE 2-5

Input/Output Diagram for Practice V--Application of Dried or Composted Sludge to Residential Lawns number of organisms remaining after one day will be $N = N_o*10^{-1.2}$, but after one hour, $N = N_o*10^{-0.05} = 0.89*N_o$ or $N_o-0.11*N_o$. The hourly inactivation factor (in this example, $-0.11*N_o$) is summed with all transfer factors for the compartment. Thus, for compartment i,

$$N(i) = N_o(i)-(TRiy)+(TRxi)-0.11*N_o(i)$$

for all applicable compartments x and y. This calculation is made once for each hour.

The concentration (pathogens per kilogram of material) is calculated by dividing the number of pathogens in the selected compartment, N(i), by the weight or volume of material in that compartment. The weight or volume of material in each compartment for which a residue-exposure risk calculation can be made is stored in the program. In some compartments the amount of material is controlled by a variable. For example, the user can supply the yield of grass or forage per m^2 of field by specifying the value of HAY [P(73)]. In other compartments the weight is constant.

Exposure estimates are made by calculating the number of ingested pathogens associated with each exposure compartment (amount ingested multiplied by concentration of pathogen). For compartments characterized by a given dose per day, the dose is converted to dose per hour, and the exposure is summed over 24 hours. For example, to simulate ingestion of soil, the daily exposure (default 0.1 g from soil and 0.1 g from crop surface in Practices II and III) is divided by 24, and the exposure estimate is done once for each hour for 24 hours. For exposures with a defined lifetime (one or more hours or the modeled lifetime of an aerosol or an operation carried out as part of the practice), the hourly exposure is summed over the relevant time period. The risk of infection is calculated by taking MID values from published literature and calculating the probability that the dose to the human receptor will reach or exceed that value, assuming a Poisson distribution of pathogens in the exposure medium.

2.2. STRUCTURE OF THE COMPUTER PROGRAM

The computer program is structured from a short main program and several subroutines. PROGRAM MODEL is found in the source code file named MAIN.FOR. Operating parameters are entered into the program through menus in subroutines INIT1, INIT2, INPUT1, and INPUT2 as well as from BLOCK DATA statements. These subroutines are read only once during each model run, and at this time the user can change the values of variables from the default values (Appendix A, Tables A-1 through A-6). If rainfall is specified, Subroutine INPUT2 calls Subroutine RAINS (source code file RAINS.FOR), which writes surface runoff and sediment transport results as a matrix to be used later. Matrix calculations are done by several subroutines called by Subroutine RAINS and found in the source code file MAT.FOR. Operating parameters for subsurface transport are entered through a menu in Subroutine GRDWTR (source code file GW.FOR). Subroutine GRDWTR may be called several times (once for each rainfall and once for each irrigation), but its menu is presented only during the dummy call. At each call, Subroutine GRDWTR averages the hourly computations for each day to give a daily average pathogen load at the specified distance. It then sums the result with results for the same day from other pulses. To avoid limitations imposed by matrix size on the length of time the model can run, this sum is held in a direct-access file to be accessed later.

After all operating parameters are entered and the rainfall computations have been completed, PROGRAM MODEL calls the evaluation subroutine appropriate for the sludge reuse practice (Practices I-V) specified via the menu. These subroutines are listed in source code files EVAL1.FOR through EVAL5.FOR. PROGRAM MODEL calls Subroutine EVALn once for each hour of operation of the model. After computing the appropriate temperature for the day of the model run, Subroutine EVAL calls each of the compartment state subroutines. All state subroutines for a given practice are contained in the same source code and object files as the corresponding EVAL subroutine. These subroutines are designated ST for "state", followed by the letters A-E to designate Practices I-V, and a number to indicate the compartment number. Thus, the subroutine designed to compute process functions and transfer factors for compartment number 11, SOIL SURFACE WATER, in Practice III would be designated Subroutine STC11. A call to Subroutine STC11 would result in computation of the process function RHO11 and transfer factors TR1104 and TR1114.

After operation of Subroutine EVALn, control is returned to PROGRAM MODEL, and N(i) and NP(i) are summed for each compartment i, as described below, to generate a new value of N(i), which is written to file PATHOUT. Infection probabilities are then calculated by Subroutine RISK (source code file INFECT.FOR), which is also called once for each hour of operation of the model.

Subroutine RISK makes use of five of its own subroutines to calculate onsite exposure to particulates and aerosols (Subroutine ONSITE), offsite exposure to particulates and aerosols (Subroutine OFFSITE), exposure through consumption of contaminated vegetables, meat or milk (Subroutine EATER), exposure through consumption of contaminated well water (Subroutine DRINKR), and exposure through incidental ingestion of contaminated pond water during a swim (Subroutine SWIMER). Each of these subroutines sums the hourly calculated exposures in the relevant compartments for 24 hours, and then calls Subroutine POISON. Subroutine POISON is based on the simplifying assumption that the probability of infection is adequately described by the Poisson distribution:

$$\mathrm{Prob(N)} = \mathrm{exp(-SUMX)}*\mathrm{SUMX}^{\mathrm{N}}/\mathrm{N!},$$

where SUMX is the summed exposure for each exposure category and N is the number of organisms to which an individual might be exposed. It is assumed that an individual who ingests at least an infective dose of pathogens is infected, and one who ingests less than an infective dose is not. The problem is, therefore, to calculate the probability that an exposed individual ingests an infective dose, or more, of the pathogen. The algorithm uses an iterative operation on the general form of the Poisson distribution:

$$\mathrm{Prob(N)} = \mathrm{Prob(N\text{-}1)}*\mathrm{SUMX/N},$$

where MID-1 is the limit value of N for non-infective doses. The probability of ingesting one or more pathogens is:

$$\mathrm{Prob(N>0)} = 1 - \mathrm{Prob(0)} = 1 - \mathrm{exp(-SUMX)}.$$

The probability of ingesting MID or more pathogens is:

$$\begin{aligned}\mathrm{Prob(N\geq MID)} &= 1 - [\mathrm{Prob(0)} + \mathrm{Prob(1)} + \ldots + \mathrm{Prob(MID\text{-}1)}] \\ &= 1 - [\mathrm{exp(-SUMX)} + \mathrm{Prob(0)}*\mathrm{SUMX}/1 + \ldots \\ &\quad + \mathrm{Prob(MID\text{-}2)}*\mathrm{SUMX/(MID\text{-}1)}]\end{aligned}$$

Because of computer system limitations on the value of exp(-SUMX), SUMX is limited to 87.0, a relatively high exposure compared to the conservative values of MID suggested for use in the model.

The probability of infection derived by Subroutine POISON is returned to the corresponding subroutine, and the infection probabilities are all returned to Subroutine RISK, which writes them on the screen and into a file whose name has been specified by the user.

Redirected standard input can be used to operate the model from a file rather than from the keyboard. However, there is a limit of one 128-byte line in the file used for standard input. Therefore, the model has been designed so that if it is to receive input data from a file, that file is opened as Unit 5 (keyboard). A single batch file cannot both initiate the program and invoke file-directed input, but redirected standard input can be used to invoke a file containing the flag for file-directed input and the name of the input file:

```
RISK < RISK1.BAT
```

where RISK1.BAT contains the lines

```
F             (flag)
INPUT1.IN     (input file name)
```

and INPUT1.IN contains the input data (see Volume I, Appendix B for an example).

2.3. COMPILING AND LINKING

During modification of the model, the computer code was converted to a form of FORTRAN 77 compatible with the Microsoft Optimizing Fortran Compiler Version 4.0. Source code files MAIN.FOR, INPUT.FOR, GW.FOR, RAINS.FOR, MAT.FOR, INFECT.FOR and EVAL1.FOR through EVAL5.FOR were compiled individually, using the /FPi option to provide for use of a math coprocessor emulation package. The math coprocessor emulator adds significantly to the flexibility of application of the program while adding only about 7500 bytes to the amount of free memory required for execution of the program. The compile command was in the form:

```
FL /c /FPi FILENAME.FOR
```

An executable module was generated by the Microsoft Overlay Linker Version 3.55, using the large-memory model and math coprocessor emulation package (library file LLIBFORE.LIB). The link command was:

```
LINK MAIN + GW + INFECT + (INPUT) + (RAINS+MAT) + (EVAL1) + (EVAL2) +
    (EVAL3) + (EVAL4) + (EVAL5)
```

which caused the creation of an overlay area for the files whose names are contained within parentheses. The memory space reserved for this model is ~532,000 bytes.

The time required for a model run depends on the length of the run and on the capabilities of the computer on which the model is run. The groundwater transport subroutine requires most of the run time.

Computation times were compared for the sample model run presented in Section 6 on several different computers. On a computer equipped with an 80287 math coprocessor and running at a speed of 12 MHz, computations required 24 seconds; a computer with an 8087 math coprocessor, running at 6.66 MHz, required 38 seconds; and a computer with no math coprocessor, running at a speed of 4.8 MHz, required nearly 18 minutes for computations.

3. OPERATING VARIABLES AND THEIR DEFAULT VALUES

3.1. VARIABLES FOR PROGRAM MODEL

Most of the variables for operation of the computer model are entered as an array designated by P(i). The variables are dimensioned as P(120) in the file PARAM.LCS. Values are assigned by block data statements in PROGRAM MODEL, which define variables for each application practice n as Pn(i). These values are then assigned to the corresponding P(i) if new values of P(i) are not entered from the menu. Values of variables that are not pathogen-specific are listed in Table A-1, whereas values of pathogen-specific P-variables are listed in Table A-2. The uses and default values of the variables are discussed below (a variable name followed by an asterisk is pathogen-specific):

Position	Name	Usage
1	ASCRS*	Pathogen density, varies with pathogen and sewage treatment. Typical values for liquid sludge are used for Practices I-III. Reported pathogen densities in composted sludge (Practices IV and V) range from undetectable (Wiley and Westerberg, 1969) to approximately $1 \cdot 10^6$ organisms/kg dry weight (U.S. EPA, 1988). Even though composted sludge intended for distribution and marketing is required to meet Class A specifications for pathogen reduction, thus having a low pathogen count (U.S. EPA, 1989b), the higher, more conservative value is suggested for use in this model. The list of proposed default values for ASCRS is contained in Table A-3. Selection of specific values for entry as ASCRS must be based on the specific processing that either the dewatered or liquid sludge has undergone prior to land application. Preferably, the user will enter actual values determined through assay of the sludge.
2	APRATE	Application rate (kg/ha): may be limited by application method. Prudent design practice involves the calculation of sludge application rates based on the nutrient (nitrogen and phosphorus) concentrations in the sludge and the nutrient requirements of the crop (U.S. EPA, 1983b, 1989b). (In some cases, the cadmium concentration in the sludge may result in an upper loading limit.) Wide variations in application rates are possible, although normal ranges are from 2000 to 70,000 kg/ha (U.S. EPA, 1983b). The user is strongly encouraged to select a value that is appropriate to the specific situation under consideration. Default values are: Practice I: 10,000 kg/ha - At 5% sludge solids, this rate represents a depth of 2 cm of liquid sludge applied to the field.

		Practices II, III: 12,500 kg/ha - equivalent to 5 hr irrigation at the default rate of 0.5 cm/hr. Practices IV, V: 25,000 kg/ha - recommended application rate for composted manure and sludge products.
3	ASCIN	Pathogen concentration (Pathogens/ha); $P(3) = P(1)*P(2)$. Value of P(3) entered from menu will override the calculated value.
4	TREG	Waiting period after application of sewage sludge before access to land or harvesting of crops. Proposed U.S. EPA Pathogen Reduction Requirements (U.S. EPA, 1989b) require that access to sludge application sites and harvesting of crops must be delayed for time periods that depend on the method of treatment and on the type of crops.
5	UPLIM	Upper limit for pathogen concentration. Sets an upper limit for the concentration of pathogens growing in infected meat. The upper compartment limit is given by number of cattle/ha [P(79)] multiplied by 270 kg beef/animal, multiplied by variable P(4). The default value ($1*10^9$ pathogens/kg meat) is considered to be a conservative value for risk estimation. An upper limit of $1*10^{36}$ pathogens for each compartment is set elsewhere in the program. This limit is related to limitations of the program and computer rather than to properties of the model.
6	APMETH	Flag for application method. -1 for spray application (default for Practices II and III), 0 for subsurface injection, +1 for surface application (default for Practices I, IV and V).
7	AREA	Area of field or garden (ha). The default value (10 ha) for commercial applications was chosen as a convenient unit. Default values for domestic applications (estimated at 0.015 ha for a garden and 0.05 ha for a lawn) are realistic areas for these applications. The user is encouraged to determine the area of the intended site of application and substitute it for this variable.
8	TEMP	Air temperature (initial value 20°C for all practices). Over a long period of time, air temperatures follow a cycle adequately described by a sine function (see Section 3.4 below). The program calculates a typical average air temperature for the time of year being modeled and saves it as variable P(8), overriding the initial value.
9	AQUIFR	Aquifer thickness (m). Represents the depth of the groundwater aquifer contaminated by leaching of pathogens from sludge. The default value of this variable (10 m) is arbitrary. The user is encouraged to substitute values reflecting the structure of the groundwater aquifer at the site being modeled.

10	POROS	Porosity of the aquifer. Represents the fraction of the aquifer thickness that is actually occupied by water. The default value of 0.3 is arbitrary and should be revised to conform to the aquifer structure at the site of application of sewage sludge. When combined with the default value of P(9) it results in a groundwater supply of $3*10^7$ L/ha.
11	FILTR8	Infiltration rate (default 2 cm/hr for all practices). Infiltration rates vary with soil type, terrain and soil moisture content. The user is encouraged to consider local soil properties and choose a value of infiltration rate that accurately describes the application site.
12	MID	Minimum infective dose, a value chosen to represent the dose of pathogen that will cause infection. This value is used along with the estimated exposure in a Poisson distribution algorithm to calculate the probability of infection. As discussed more fully in the text, the MID is highly dependent on the pathogen, the route of exposure and the sensitivity of the exposed individual. Values of 1 infectious unit of virus or 1 parasite egg are reasonable; a range of 10^2 to as many as 10^6 organisms has been reported as reasonable for enteric bacterial pathogens. The default value of 10 is probably very conservative for Salmonella; the default value for Ascaris and enterovirus is 1.
13	TRAIN	Flag or variable for time when rainfall begins (hr). The default value (-2) is used as a flag to indicate no rainfall. If the user calls for rainfall from the menu, an array is created in which the time of each rainfall is stored. When the rainfall subroutine calculates the results of each rainfall, it assigns the time of that rainfall to variable P(13). Thus the value of P(13) changes during operation of the model.
14	RDEPTH	Rainfall depth (cm). Represents the amount of rain at each rainfall. The default value (5 cm) can be changed from the menu for each rainfall. This value is at or slightly below the expected 5-year maximum 2-hour rainfall for much of the agricultural portion of the United States (U.S. EPA, 1985).
15	TK	Time since last rainfall began. This variable is used as a counter for the number of hours since the last rainfall began. It is set to 0 in compartment 4 when the condition (T .EQ. TRAIN) is met and is incremented by 1 each hour thereafter. At the completion of the subroutine representing Compartment 4, P(15) is reset to the new value of TK. TK is used to indicate the times of transfer of pathogens by leaching with rainwater from SOIL SURFACE (4) to SOIL SURFACE WATER (11) and SUBSURFACE SOIL (8), from SUBSURFACE SOIL (8) via GROUNDWATER (9) to IRRIGATION WATER (10) and OFF-SITE WELL (12) and from SOIL SURFACE WATER (11) to CROP SURFACE (14).

16	TIRRG	Time since last irrigation began. This variable is used as a counter for the number of hours since the last irrigation began. It is set to 0 in compartment 4 when the condition (T .EQ. TRAIN) is met [TRAIN = P(13)]. Thereafter it is set each hour to the lesser of TK [P(15)] or the time since the last irrigation. At the completion of the subroutine representing Compartment 4, P(16) is reset to the new value of TIRRG. TIRRG is used to indicate the times of transfer of pathogens by leaching with irrigation water from SOIL SURFACE (4) to SOIL SURFACE WATER (11) and SUBSURFACE SOIL (8), from SUBSURFACE SOIL (8) via GROUNDWATER (9) to IRRIGATION WATER (10) and OFFSITE WELL (12) and from SOIL SURFACE WATER (11) to CROP SURFACE (14).
17	IRMETH	Flag for irrigation method: 0 for spray irrigation, +1 for ditch irrigation. The default condition (spray irrigation) represents the worst case; ditch and spread-flow irrigation should not create aerosols for onsite or offsite inhalation exposures as spray irrigation does and ditch and spread-flow irrigation would be expected to be controlled to prevent runoff and sediment transport.
18	DILIRR	Irrigation source. Represents fraction of irrigation water supplied by a source whose pathogen concentration is given by COUNT [variable P(22)]. Default values, 0 for Practice I, 1 for Practices II and III. Use of a mixture of contaminated and uncontaminated water for irrigation is modeled by choosing a value of DILIRR between 0 and 1.
19	NIRRIG	Number of irrigations per week. Represents the number of times weekly the crop will be irrigated at a rate given by variable IRRATE [P(20)] in a total amount given by variable DEPTH [P(21)]. The default value of this variable (2) is arbitrary. The user is encouraged to substitute values reflecting farming practices in use at the application site.
20	IRRATE	Irrigation rate (cm/hr). Represents the rate at which irrigation water is applied. The default value is 0.5 cm/hr. The user is encouraged to change this value to conform to farming practices in use at the application site.
21	DEPTH	Depth of irrigation water (cm). Default value 2.5 cm. Actual values will depend on local soil type, soil moisture, temperature, wind and type of crop. The user is encouraged to enter a value appropriate for the specific application.
22	COUNT	Pathogen concentration in irrigation sludge (pathogens/kg). Assumed to be negligible in Practices IV and V because it is assumed that home use options will include irrigation with uncontaminated water. For Practices II and III, the default condition is irrigation with liquid sludge, with a pathogen concentration equal to ASCRS [variable P(1)]. Although

		contaminated water may not be used directly on crops for commercial production, the default value for Practice I is left as ASCRS to enable modeling of irrigation with liquid sludge. DILIRR [variable P(18)] is set to 0 in Practice I to prevent transfer of pathogens to commercial crops by irrigation.
23	TWIND	Time of windstorm (hr). Time at which the windstorm occurs. The model is limited to a single windstorm, whose intensity is given by variable WINDSP [P(25)] and whose duration is given by variable DWIND [P(24)]. The default value (60 hr) was chosen to represent exposure early in the model run, when exposures would be high.
24	DWIND	Duration (hrs) of the windstorm that begins at time TWIND [P(23)]. Intensity (wind speed) of the storm is given by variable WINDSP [P(25)]. The default value of this variable (6 hr) is arbitrary. The user is encouraged to substitute values reflecting local extremes of wind.
25	WINDSP	Wind speed during windstorm (m/sec). Represents the intensity of the windstorm beginning at time TWIND [P(23)] and having duration DWIND [P(24)]. The default value of this variable (18 m/sec) is arbitrary. The user is encouraged to substitute values reflecting local extremes of wind.
26	EPSMLT	Particle size multiplier. Dimensionless constant used in calculation of the particulate cloud generated by tilling. The particle size multiplier varies with particle size range as follows (U.S. EPA, 1985): Size range <30 μm <15 μm <10 μm <5 μm <2.5 μm EPSMLT 0.33 0.25 0.21 0.15 0.10 As a worst-case estimate, the default value is set at 0.33.
27	ESILT	Fractional silt content of soil. This constant raised to the 0.6 power is used in calculation of the particulate cloud generated by tilling (U.S. EPA, 1985). The value of 0.4 corresponds to a loam or clay loam soil (Brady, 1974).
28	EHT	Height of box model (m). Represents the maximum height of a compartment of uniformly mixed particulates generated by tilling. The default value of this variable (2 m) is intended to represent the height of the nose and mouth of a tractor operator tilling the sludge into the soil or cultivating the crop. The assumption of uniform mixing means that the calculated concentration of pathogens in particulates inhaled or ingested will probably be higher than is realistic; it does, however, provide a worst-case estimate as well as a simplification of the calculation compared to detailed predictions of the nature of the particulate cloud.
29	SCRIT	Critical wind speed (m/sec). There is a threshold wind speed

		below which wind erosion does not occur. That speed varies with soil type, terrain and amount of cover vegetation, and, because of large variations in wind speed close to the ground, is typically corrected to a height of 7 m. The default threshold wind speed is 7.5 m/s (U.S.EPA, 1985).
30	COVER	Fraction of ground surface covered by vegetation. Used as a constant in the calculation of concentration of airborne particulates generated by the windstorm. This value represents the fraction of surface soil available to be entrained by the wind; soil with ground cover is not accessible to the wind because vegetation disperses the wind's kinetic energy. The default values of this variable (0 in Practices I and IV and 0.9 in Practices II, III and V) reflect the difference between a newly planted field or garden and a field or lawn with a standing crop of grass or other forage. The user is encouraged to change this value to conform to anticipated conditions at the time of the modeled windstorm.
31	AEREFF	Efficiency of aerosol formation. Represents fraction of liquid spray released as aerosol, highly dependent on design of irrigator nozzles, flow rate and pressure. Default value 0.001 (Sorber et al., 1984).
32	BREEZE	Normal wind speed (m/sec). Represents a prevailing wind which carries particulate and droplet aerosols offsite after tilling and irrigation. The default value (4 m/sec) is a gentle breeze. This value can be varied to determine whether there should be a maximum allowable wind for generation of aerosols by irrigation or tilling.
33	HT	Height of receptor downwind (m). The z component of the particulate and droplet aerosol exposure calculations. The default value (1.6 m) is intended to represent the height of the nose and mouth of an average field worker or offsite person who may inhale or ingest the aerosol-borne pathogens.
34	ANDAY	Day in annual temperature cycle. The day of the year on which the model is to begin, adjusted by indexing to the appropriate point in the cyclical temperature equation. For details, see Section 4.4.
35	TMAX	Maximum (July) monthly average temperature (°C). Sets the upper limit of the temperature cycle. This value must be supplied by the user of the model and can be obtained from local weather records or from published regional records (NOAA, 1981).
36	TMIN	Minimum (January) monthly average temperature (°C). Sets the lower limit of the temperature cycle. This value must be supplied by the user of the model and can be obtained from local weather records or from published regional records (NOAA,

		1981).
37	SLOPES*	Process function parameter. Represents the slope of a straight line fitted to a log transform of data points taken from published literature (Crane and Moore, 1986; Kibbey et al., 1978) on die-off rates of microbes in moist soil at different temperatures. This variable is used with TEMP [P(8)] and NTRCPS [P(38)] to calculate a temperature-dependent die-off rate in compartments in which moist soil is represented (1, 4, 8, 14). Values are organism-specific and are listed in Table A-2. Default values are listed for *Salmonella* and enterovirus; values for *Ascaris* have not been derived because of data limitations.
38	NTRCPS*	Process function parameter. Represents the y-intercept of a straight line fitted to a log transform of data points taken from published literature (Crane and Moore, 1986; Kibbey et al., 1978) on die-off rates of microbes in moist soil at different temperatures. This variable is used with TEMP [P(8)] and SLOPES [P(37)] to calculate a temperature-dependent die-off rate in compartments in which moist soil is represented (1, 4, 8, 14). Values are organism-specific and are listed in Table A-2. Default values are listed for *Salmonella* and enterovirus; values for *Ascaris* have not been derived because of data limitations.
39	SLOPEP*	Process function parameter. Represents the slope of a straight line fitted to a log transform of data points taken from published literature (Crane and Moore, 1986; Kibbey et al., 1978) on die-off rates of microbes in dry particulates at different temperatures. This variable is used with TEMP [P(8)] and NTRCPP [P(40)] to calculate a temperature-dependent die-off rate in Compartment 5, in which dry particulates are represented. Values are organism-specific and are listed in Table A-2. Default values are listed for *Salmonella*; values for *Ascaris* and enterovirus have not been derived because of data limitations.
40	NTRCPP*	Process function parameter. Represents the y-intercept of a straight line fitted to a log transform of data points taken from published literature (Crane and Moore, 1986; Kibbey et al., 1978) on die-off rates of microbes in dry particulates at different temperatures. This variable is used with TEMP [P(8)] and SLOPEP [P(39)] to calculate a temperature-dependent die-off rate in Compartment 5, in which dry particulates are represented. Values are organism-specific and are listed in Table A-2. Default values are listed for *Salmonella*; values for *Ascaris* and enterovirus have not been derived because of data limitations.
41	ASLSUR	Transfer fraction: Application to soil surface. This variable represents the fraction of pathogens that reach the soil surface after application. The default value assigned is 0.9, which is an unsupported estimate.

42	FSSUR	Transfer fraction: Application to subsurface soil. For efficient application methods, this value will be 1 when subsurface injection is used.
43	FRRAIN	Transfer fraction: Soil surface to surface runoff. Represents suspension of pathogens from soil surface in surface water which subsequently runs off the site to a receptor pond. Default values are not used because values are generated by Subroutine RAINS, so that there is a separate value of FRRAIN for each hour after the first rainfall.
44	SUBSOL*	Transfer fraction: Soil surface to subsurface soil. Represents leaching of pathogens from soil surface to subsurface soil by infiltrating water. Suggested values are pathogen-specific and are listed in Table A-2.
45	SUSPND*	Transfer fraction: Soil surface to soil surface water. Represents suspension of pathogens from soil surface into soil surface water after rainfall or irrigation. Suggested values are pathogen-specific and are listed in Table A-2. These values are estimates based on evidence from field and laboratory studies (Burge and Enkiri, 1978; Drewey and Eliassen, 1968; Gerba el al., 1975; Marshall, 1971; Reddy et al., 1981).
46	FCROP1	Transfer fraction: Soil surface to crop 1. Represents transfer of pathogens in surface soil to surface of aboveground crop (Practices I and IV only), by wind or at the time of harvesting. The default value ($1*10^{-8}$) is an unsupported estimate.
47	FCROP2	Transfer fraction: Soil surface to crop 0. Represents transfer of pathogens in surface soil to surface of on-ground crop (Practices I and IV only) by wind or at the time of harvesting. The default value (0.006) is an unsupported estimate.
48	FCROP3	Transfer fraction: Soil surface to crop -1. Represents transfer of pathogens in surface soil to surface of below-ground crop (Practices I and IV only) at the time of harvesting. The default value ($1*10^{-3}$) is an unsupported estimate.
49	FCROP4	Transfer fraction: Soil surface water to crop 1. Represents transfer of pathogens suspended in soil surface water to surface of aboveground crop by splashing of irrigation water or rainwater. The default value ($1*10^{-4}$) is an unsupported estimate.
50	FCROP5	Transfer fraction: Soil surface water to crop 0. Represents transfer of pathogens suspended in soil surface water to surface of on-ground crop by splashing of or immersion in irrigation water or rainwater. The default value (0.012) is an unsupported estimate.

51	FCROP6	Transfer fraction: Soil surface water to crop -1. Represents transfer of pathogens suspended in soil surface water to surface of below-ground crop by percolation of irrigation water or rainwater. The default value is 0 because below-ground crops are not normally expected to contact soil surface water.
52	FCROP7	Transfer fraction: Subsurface soil to crop -1. Represents transfer of pathogens in subsurface soil to surface of below-ground crop by adherence of soil to the crop. The default value ($2*10^{-4}$) is an unsupported estimate.
53	FRGRND*	Transfer fraction: Subsurface soil to groundwater. Represents transfer of pathogens in subsurface soil to groundwater. The default values (pathogen-specific, Table A-2) are estimates based on field and laboratory studies (Reddy et al., 1981; Sorber and Moore, 1987).
54	SSWTCS*	Transfer fraction: Soil surface water to crop surface. Represents transfer of pathogens suspended in soil surface water to the surface of grass or other forage. Suggested values are pathogen-specific and are listed in Table A-2.
55	PSTMG	Transfer fraction: Grass removed at each mowing (Practice V only). Represents the fraction of pathogens on the grass surface removed when the lawn is mowed. The default value (0.5) is an unsupported estimate.
56	CSTSS	Transfer fraction: Crop surface to soil surface, represents pathogen-contaminated soil falling from surface of crop. Default value of 0.01/hr is an unsupported estimate.
57	SSTCS	Transfer fraction: Soil surface to crop surface. Represents transfer of pathogens in surface soil to crop surface (Practices II and III only) as a result of wind or disturbance by grazing animals. The default value ($1*10^{-5}$) is an unsupported estimate.
58	CSTSSW	Transfer fraction: Crop surface to soil surface water, represents pathogens washed off crop surfaces by rain or irrigation water. Default values (0.75 for Practices I and IV, 0.5 for Practices II, III and V) are unsupported estimates.
59	DTCTMT	Transfer fraction: Animal consumption to meat, represents a transfer of pathogens in a systemically infected animal directly to meat. Systemic infection with an enteric bacterial pathogen would make the animal acutely ill. Because it is unlikely that meat from an animal with an acute illness would be used as a commercial product, the default value is zero. Transfer of some parasites to meat is very likely if the animal is harboring reproductive forms of the parasite, although it is not clear what number should be used to reflect the ratio of infective forms in meat to reproductive forms in the animal. It is possible that one or a few reproducing parasites could result in heavy

		infestation of the animal's tissues. The user has the option of changing the value of DTCTMT to reflect any hypothetical transfer of pathogens from the blood stream to meat.
60	DTCTMK	Transfer fraction: Animal consumption to milk, represents a transfer of pathogens in a systemically infected cow directly to milk. The default value is zero because it is unlikely that such a transfer would occur. In addition, systemic infection with an enteric pathogen would make the animal acutely ill; it is unlikely that milk from a cow with an acute illness would be used as a commercial product. It is possible that other pathogens, for example, pathogens causing tuberculosis, might be passed to milk. The user has the option of changing the value of DTCTMK to reflect any hypothetical transfer of pathogens from the blood stream to milk.
61	TMTSS	Transfer fraction: Manure to soil surface. Represents daily contamination of the surface soil by a fraction of the total manure output of infected cattle in Practice II. This variable is used with the concentration of pathogens in manure to calculate the number of pathogens returning to the soil after being ingested with forage, soil or runoff water. The default value of this variable (0.7) is arbitrary. The user is encouraged to substitute values reflecting ground cover type and density, farming practices or other factors that may apply.
62	TMTH	Transfer fraction: Manure to hide. Represents daily contamination of the hide of beef cattle by a fraction of the total manure output. This variable is used with the concentration of pathogens in manure to calculate the number of pathogens contaminating the hide of the animal as a route to contamination of meat at the time of slaughter in Practices II and III. The default value of this variable (0.001) is arbitrary. The user is encouraged to substitute values reflecting anticipated farming and slaughtering practices.
63	TMTU	Transfer fraction: Manure to udder. Represents surface contamination of the udders of dairy cows with manure-borne pathogens. A fraction of pathogens (default 0.001) from MANURE N(19) is transferred hourly to UDDER N(22). Pathogens are not expected to be present in uninfected cattle (N(19) = 0). Therefore, the number of pathogens in UDDER is zero unless infection of the cow has occurred.
64	HTM	Transfer fraction: Hide to meat (Practices II and III only). Represents surface contamination of meat by gut contents at the time of slaughter. The default value (0.1) is an unsupported estimate.
65	UTM	Transfer fraction: Udder to milk. Represents a fraction of pathogens from the udder of a dairy cow that is transferred to milk when manure on the udder falls into the milk during

		milking. The default value (0.05) is an unsupported estimate.
66	CROP	Flag for type of crop being grown: -1 for below-ground crop (carrots), 0 for on-ground crop (zucchini), +1 for aboveground crop (tomatoes). Default +1 for Practice I. A mixture of crops for Practice IV is reflected by the variables PLNT1 [P(74)], PLNT2 [P(75)] and PLNT3 [P(76)].
67	TCULT	Flag or variable for cultivation time (hr). Represents cultivation of the field or garden in which food crops are being produced. The default value (-2) serves as a flag to indicate no cultivation, the value 0 serves as a flag to indicate cultivation every two weeks and any integer greater than 0 indicates the time at which a single cultivation occurs.
68	TCROP	Time crop surface is present (hr). Represents the time at which the crop surface is present. Exposure by contact with or ingestion of crop surface is not possible before this time. The default values are related to the crops in each practice. They are: 720 hours for aboveground crop in Practices I and IV; 0 hours for preexisting forage crop in Practices II and III; and 240 hours for newly seeded grass in Practice V.
69	THARV	Harvest time (hrs). Time after initiation of the model at which the crop is harvested. This time will depend on the crop and on the length of time between initiation of the model (application of sludge) and planting of the crop. The default values (1800 for Practice I, 720 for Practice III and 1680 for Practice IV) are intended to represent maturation times for crops to be grown in these practices, but the user is encouraged to enter values appropriate to the situation being modeled. Harvesting is not allowed to occur until after the waiting period specified by the U.S. EPA Pathogen Reduction Requirements (U.S. EPA, 1989b), i.e., when THARV $\geq$ TCEASE+TREG, where TCEASE is the time at which sludge application stops and TREG [P(4)] is the specified waiting period.
70	YIELD1	Yield of tomatoes (g/ha). The default value ($2.5*10^7$ g/ha) is based on reports of agricultural production.
71	YIELD2	Yield of zucchini (g/ha). The default value ($2.5*10^7$ g/ha) is based on seed suppliers' estimates.
72	YIELD3	Yield of carrots (g/ha). The default value ($1*10^6$ g/ha) is based on seed suppliers' estimates.
73	HAY	Grass present in field, or hay yield (kg dry weight/m^2, Practices II and III only). The default value (1.6 kg/m^2) is based on estimates of grassland production in temperate climates (Whittaker, 1975).
74	PLNT1	Fraction of plant surface in aboveground crop. Used with

		variable YIELD1 [P(70)] to calculate concentration of pathogens in harvested aboveground crops PPG1 for determination of the composite pathogen concentration PPG [P(77)] in Practice IV. The default value of this variable (0.4) is arbitrary; the user is encouraged to change it to reflect gardening applications in use at the application site.
75	PLNT2	Fraction of plant surface in on-ground crop. Used with variable YIELD2 [P(71)] to calculate concentration of pathogens in harvested on-ground crops PPG2 for determination of the composite pathogen concentration PPG [P(77)] in Practice IV. The default value of this variable (0.3) is arbitrary; the user is encouraged to change it to reflect gardening applications in use at the application site.
76	PLNT3	Fraction of plant surface in below-ground crop. Used with variable YIELD3 [P(72)] to calculate concentration of pathogens in harvested below-ground crops PPG3 for determination of the composite pathogen concentration PPG [P(77)] in Practice IV. The default value of this variable (0.3) is arbitrary; the user is encouraged to change it to reflect gardening applications in use at the application site.
77	PPG	Pathogen concentration on crop (pathogens/g). Used in exposure calculations for consumption of vegetable crops in Practices I and IV. This variable is calculated at the time of harvesting by these equations: Practice I - $PPG = N(16)/YIELD$ Practice IV - $PPGi = N(16)*PLNTi/YIELDi, \; i=1,2,3$ $PPG = PPG1+PPG2+PPG3$ where N(16) is the population of compartment 16 (CROP), PLNTi is the fraction of crop surface represented by crop i [variables P(74), P(75), and P(76)] and YIELDi is the yield in grams/ha of crop i [P(70), P(71) and P(72)]; i is 1 (aboveground crop), 2 (on-ground crop) or 3 (below-ground crop).
78	CATTLE	Flag for type of cattle. -1 for beef cattle and +1 for dairy cattle. The default value (+1) was arbitrarily chosen to model dairy farming practices.
79	COWS	Herd size. Represents the number of cattle per hectare grazed on sludge-amended pasture (Practice II) or given feed prepared from forage grown on sludge-amended pasture (Practice III). The default value (12) is arbitrary, and the user is encouraged to substitute a value appropriate to the farming practice in use at the application site.
80	STORAG	Length of forage storage (days). Represents the length of time feed prepared from forage is stored before it is fed to the

		cattle. The default value (720 hours) is arbitrary and should be changed to reflect farming practices in use at the application site.
81	FORAG	Forage consumed per cow per day (kg). The default value (7 kg/day) is based on suggestions from animal nutritionists.
82	ALFALF	Percent of feed which is harvested crop. Variable to be determined by farming practices. Default value 30%.
83	SCNSMP	Soil consumed per cow per day (kg). Represents soil ingested on the surface of pasture or prepared forage. The default value (1.1 kg) is based on estimates by animal nutritionists.
84	FATTEN	Number of hours cattle are to be fed forage before slaughter (Practice III only). The default value is 720 hours. The user is encouraged to change this value to reflect farming practices in use at the application site.
85	TSLOTR	Flag or variable for time of slaughter (day). The default value (-2) serves as a flag to indicate no slaughter, because the default condition for Practices II and III is for raising dairy cattle.

3.2. VARIABLES AND DEFAULT VALUES FOR SUBROUTINE RISK

Variables for Subroutine RISK are declared in the file RISKK.LCS, which is used as a common file. The variables are initialized in the BLOCK DATA BLKDAT sections of PROGRAM MODEL (source code file MAIN.FOR). They can then be changed by the user from a menu in Subroutine INPUT2. They are used in computations in subroutines VEG, MEAT and MILK through Subroutine RISK, via its associated Subroutine EATER. The variables and their uses are described below.

3.2.1. Subroutine VEG. Exposure to pathogens in food crops produced in sludge-amended soil is modeled in Practices I and IV. The number of pathogens/gram crop is calculated by Subroutine VEG from the pathogen content of Compartment 16, CROP, and is the figure used by the vegetable-exposure risk calculation.

A full 24-hour pathogen exposure is computed by Subroutine VEG, rather than a 1-hour exposure. Pathogen concentrations are determined as number/g. Average daily consumption (± standard deviation) is estimated as 81 (±55) g for aboveground crop (tomatoes), 80 (±76) g for on-ground crop (zucchini) and 43 (±40) g for below-ground crop (carrots) (U.S. FDA, 1978).

Before being consumed, vegetables normally are processed in some way. Included in the program is a series of user-selectable processing steps. The user has the option of choosing any or all processing steps and of specifying some conditions within processing steps. The parameters that control processing are listed in Table A-4.

3.2.1.1. STORAGE. Harvested vegetables are often stored before being processed. The user selects for storage by setting ISTRH=1. The user may specify the temperature of storage by assigning a value to TEMP2. The default value of this variable is 7°C. This temperature is within the recommended range for all three of the modeled vegetable types (Jay, 1978; Weiser et al., 1971). Since the relative humidity of storage is assumed to be between 85 and 90%, the storage temperature controls the process functions for this step. Process functions (RHOs) in the vegetable exposure risk calculation are used in a different manner than in the transport model, in which they are used to calculate hourly equivalents of exponential changes. In this case, the RHOs are part of the equation:

$$N(2) = N(1)*\exp(RHO*TSTR2)$$

where:

N(2) = number of pathogens remaining after storage

N(1) = number of pathogens entering the process series

TSTR2 = duration of unprocessed vegetable storage (hours).

The RHO values for this step are:

Salmonella:	0.0/hour, for TEMP2 ≤ 20. No change is assumed for *Salmonella* during cold storage.
	0.07/hour, for 20 < TEMP2 ≤ 45. Growth of *Salmonella* in soil clinging to vegetables is assumed to occur at one-half the rate for *E. coli* in sterile compost (Morris et al., 1979).
	-3.45/hour, for TEMP2 >45 (Brandon and Neuhauser, 1978; Wiley and Westerberg, 1969)
Ascaris:	-0.0005/hour, for TEMP2 ≤ 40 (Veerannan, 1977)
	-1.54/hour, for TEMP2 >40 (Brandon, 1978; Stern, 1974)
Enteroviruses:	-0.00087/hour, for TEMP2 ≤ 15 (Yeager and O'Brien, 1979)
	-0.005/hour, for 15 < TEMP2 <45 (Duboise et al., 1976; Yeager and O'Brien, 1979)
	-0.38/hour, for TEMP2 ≥ 45 (Ward et al., 1976; Younger, 1956)

The user may specify a value for TSTR2, the time of unprocessed vegetable storage, which defaults to 1 week. Setting either ISTRH or TSTR2 to zero will eliminate storage from vegetable-exposure risk calculation.

3.2.1.2. WASHING. Vegetables are usually washed before being commercially processed or before being cooked or eaten raw in the home. Both types of washing are designed to remove visible dirt and will also remove 90% of the pathogens clinging to fresh vegetables (Hersom and Hulland, 1964). Selecting the washing step by setting IWASH=1 (the default condition) leads to a 90% reduction in pathogens associated with the vegetables being processed.

3.2.1.3. BLANCHING. Blanching follows washing in commercial canning and freezing operations and is designed to clean foods, to shrink them by removing gases, and to inhibit enzymes (Hersom and Hulland, 1964). The process involves temperatures of 82-93°C for 3-5 minutes. No relevant studies on the effects of commercial blanching operations on the model pathogens were found in the literature review. The effects of this process, as simulated in the risk calculation, were chosen to be a conservative estimate of reductions in pathogen populations due to the high temperatures involved. When IBLAN=1, the number of Salmonella is reduced by 5 orders of magnitude (Jay, 1978), the number of Ascaris by 1 order of magnitude, and the number of enteroviruses by 2 orders of magnitude. The default value of IBLAN is 0, representing no reduction of pathogens by blanching.

3.2.1.4. CANNING. Commercial canning is a 4-step process which includes 1) filling cans; 2) exhausting cans; 3) heat processing; and 4) cooling. Only the effects of heat processing are considered in the canning step of the vegetable-exposure risk calculations. The temperature and duration of canning processes vary according to product but are specifically designed to reduce an assumed Clostridium botulinum spore population by 11 orders of magnitude (Hersom and Hulland, 1964; Weiser et al., 1971). An acidic food, such as tomatoes, might be heated to 120°C for 6 minutes while a low-acid food, such as zucchini or carrots, might be heated to 126.7-148.9°C for a similar length of time (Hersom and Hulland, 1964). None of the modeled pathogens are as heat resistant as Clostridium botulinum spores, but no data on the reduction of these organisms during canning were found. Therefore, the program reduces each pathogen population by 11 orders of magnitude when canning is included in the processing series.

Setting the variable ICANG=1 flags for canning (the default value is 0). The user may also specify an entire processing sequence that includes canning by setting ICAN=1. The canning sequence includes the effects of unprocessed vegetable storage, washing, blanching, canning, storage of cans and cooking on the pathogens associated with harvested vegetables.

3.2.1.5. FREEZING. A large portion of both home-grown and commercial crops are frozen. Step 6 of the vegetable-exposure risk calculation simulates freezing and the subsequent thawing of vegetables. The Salmonella population, if present, is reduced by 2 orders of magnitude (Gunderson and Rose, 1948; Ray et al., 1972), while there is no change in the number of Ascaris (Cram, 1924) or poliovirus. Freezing is flagged by setting IFREG=1 or by setting IFREE=1. IFREE, like the variable ICAN, specifies an entire processing sequence. The freezing sequence includes storage of unprocessed vegetables, washing, blanching, freezing, frozen storage and cooking. Canned foods are not usually frozen, but the effects of both processes may be included in the processing sequence by setting both ICANG and IFREG to 1. (The default value for IFREG is 0. The no-canning sequence is the default calculation.)

3.2.1.6. POST-PROCESSING STORAGE. Following canning or freezing most vegetable products are stored for a second time on supermarket shelves and in freezers. The duration and temperature of processed vegetable storage may be specified by the user. The default value of TSTR7 (duration of storage) is 1 month. Two variables are provided for the temperature parameter. TMP7N has a default value of 20°C and is used when any combination of processing steps not including freezing is specified. TMP7F has a default value of -4°C and is used when freezing is included in a processing sequence (as in step 2 above). The RHO values for this step are (TMP7_ = TMP7N or TMP7F):

Salmonella: -0.000014/hour, for TMP7_ ≤0.0 (Gunderson and Rose, 1948)

0.0/hour, for 0.0 < TMPT_ <20

0.07/hour, for 20 ≤ TMPT_ ≤45 (Morris et al., 1979)

-3.45/hour, for TMPT_ >45 (Brandon and Neuhauser, 1978; Wiley and Westerberg, 1969)

Ascaris: -0.0005/hour, for TMPT_ ≤40 (Veerannan, 1977)

-1.54/hour, for TMPT_ >40 (Brandon, 1978; Stern, 1974)

Enteroviruses: -0.00087/hour, for TMPT_ ≤15 (Yeager and O'Brien, 1979)

-0.005/hour, for 15 < TMPT_ <45 (Duboise et al., 1976; Yeager and O'Brien, 1979)

-0.38/hour, for TMPT_ ≥45 (Ward et al., 1976; Younger, 1956)

Vegetables can be eaten raw or cooked. The vegetable-exposure risk calculation assumes that fresh or processed vegetables are cooked in a small amount of liquid at 100°C for 5 minutes if ICOOK=1. Little information was found on the effects of cooking on the representative pathogens. Therefore, the process functions for this step are variables and may be changed by the user to reflect any available data. It is generally assumed that 15 minutes at 75°C will kill all nonspore-forming bacteria in a food (Guthrie, 1972). The default values for COOKS, COOKA and COOKP (the reduction of Salmonella, Ascaris and enteroviruses) are 30, 5 and 5 orders of magnitude, respectively. The value for Salmonella is estimated from a D_{70} value of 1 second (Jay, 1978). The value for Ascaris is extrapolated from data at 80°C (Cram, 1943). The value for enteroviruses is extrapolated from data at 45°C (Ward and Ashley, 1977). The user might wish to change the definition of cooking and simulate higher temperatures or include the protective effects of oils or other process-added materials. These changes can be simulated by using different values for the COOK variables.

3.2.2. Subroutine MEAT. Pathogen exposure through meat consumption occurs when the beef cattle option is selected in Practices II and III. This exposure risk calculation is performed on the pathogen population transferred to MEAT at the time of slaughter.

3.2.2.1. SLAUGHTER. The variable TSLOTR determines the day on which slaughter occurs. The actual transfers take place 24 hours after the time specified by TSLOTR [P(85)]. The calculation is made once. As with vegetables, a full 24-hour pathogen exposure is computed by Subroutine MEAT, rather than a 1-hour exposure, because this subroutine is called only once. Pathogen exposure through meat consumption is determined by multiplying the concentration of pathogens in meat by an average quantity consumed, i.e., 0.256 kg/day (U.S. FDA, 1978).

When a steer is slaughtered, the carcass is washed with a solution of hot water and chlorine, covered with a shroud and cooled to 0°C (Fields, 1979). The effects of this treatment on meat-associated pathogens are not included in either the process functions or the exposure risk calculation. Treatment after slaughter is designed to reduce surface contamination. Since meat may be directly contaminated by Salmonella and there is no way of distinguishing the source of contamination after transfer to the risk calculation, pathogens associated with meat are treated as if spread evenly throughout the product rather than concentrated on the outside and cut surfaces.

3.2.2.2. STORAGE. The meat exposure risk calculation assumes that raw meat is stored after slaughter. The user may specify the duration and temperature of storage by assigning values to TSTM2 and TMP2M. These variables are listed in Table A-4. The default value for TSTM2 is 1 month, and the default value for TMP2M is 4°C to model the cold storage common after slaughter (Fields, 1979).

The effects of storage on meat-associated pathogens are the same as on vegetable-associated pathogens. The RHO values for this step are used in the manner described above and are as follows:

Salmonella: 0.0/hour, for TMP2M $\leq$20. No change is assumed for Salmonella during cold storage.

0.07/hour, for 20 < TMP2M $\leq$45. Growth of Salmonella is assumed to occur at one-half the rate for E. coli in sterile compost (Morris et al., 1979)

-3.45/hour, for TMP2M >45 (Brandon and Neuhauser, 1978; Wiley and Westerberg, 1969)

Ascaris: -0.0005/hour, for TMP2M <40 (Veerannan, 1977)

-1.54/hour, for TMP2M $\geq$40 (Brandon, 1978; Stern, 1974)

Enteroviruses: -0.00087/hour, for TMP2M $\leq$15 (Yeager and O'Brien, 1979)

-0.005/hour, for 15 < TMP2M <45 (Duboise et al., 1976; Yeager and O'Brien, 1979)

-0.38/hour, for TMP2M $\geq$45 (Ward et al., 1976; Younger, 1956)

3.2.2.3. FREEZING. Commercially processed meat is usually frozen as a way of reducing the possible transfer of parasites to the consumer. Home-processed meats are usually frozen to keep the meat until it is consumed. Furthermore, with the distances between processing plant and consumer, most meat is frozen at some time. The effects of freezing on meat-associated pathogens are the same as those given for freezing of vegetables. The Salmonella population, if present, is reduced by 2 orders of magnitude (Gunderson and Rose, 1948; Ray et al., 1972); there is no change in the number of Ascaris (Cram, 1924) or enterovirus.

The frozen meat is assumed to be stored again. The user may specify the duration of this second storage period by assigning a value to TSTR4; the default value is 5 days. The temperature of storage is also controllable. The default value of TEMP4 models frozen storage at 0.0°C. The user may specify a value to indicate storage at room temperature if the effects of improper storage are to be simulated. The RHO values for this storage step are similar to those given for the first storage period but include a value for the effects of long-term frozen storage on Salmonella. The values are:

Salmonella: -0.00014/hour, for $\text{TEMP4} \leq 0.0$ (Gunderson and Rose, 1948)

0.0/hour, for $0.0 < \text{TEMP4} < 20$

0.07/hour, for $20 \leq \text{TEMP4} \leq 45$ (Morris et al., 1979)

-3.45/hour, for $\text{TEMP4} > 45$ (Brandon and Neuhauser,1978; Wiley and Westerberg, 1969)

Ascaris: -0.0005/hour, for $\text{TEMP4} < 40$ (Veerannan, 1977)

-1.54/hour, for $\text{TEMP4} \geq 40$ (Brandon, 1978; Stern, 1974)

Enteroviruses: -0.00087/hour, for $\text{TEMP4} \leq 15$ (Yeager and O'Brien, 1979)

-0.005/hour, for $15 < \text{TEMP4} < 45$ (Duboise et al., 1976; Yeager and O'Brien, 1979)

-0.38/hour, for $\text{TEMP4} \geq 45$ (Ward et al., 1976; Younger, 1956)

3.2.2.4. COOKING. Thawed meat (the freezing process functions include the effects of thawing on the model pathogens) may be eaten raw or may be cooked. When ICOOK=1, the meat-exposure risk calculation assumes that meat is cooked at 100°C (as long as food is moist this is the highest temperature reached) (Weiser et al., 1971) for 5 minutes. The short time period reflects the length of time at temperature and disregards the effects of heat while the product is reaching temperature and later cools. Little information was found on the effects of cooking on the representative pathogens. Therefore, the process functions for this step in meat processing are variables and may be changed by the user to reflect data available. The default value for COOKS, the reduction in Salmonella, is 30 orders of magnitude. The default values for COOKA and COOKP, the reduction in Ascaris and enteroviruses, respectively, are 5 orders of magnitude. These values are the same as those used in the vegetable exposure risk calculation cooking step. They are extrapolations from data obtained at lower temperatures (Cram, 1943; Jay, 1978; Ward and Ashley, 1977). The values assigned to the cooking variables may be decreased to simulate partial cooking, such as a rare steak. Assigning a value of zero to the appropriate cooking process function variable or assigning a value of zero to ICOOK will simulate consumption of raw meat.

3.2.3. Subroutine MILK. Pathogen exposure through milk consumption occurs when the dairy cow option is selected in Practices II and III. Each cow delivers 7.5 L of milk per milking. The pathogen load transferred to milk is distributed evenly throughout the entire quantity of milk collected from the dairy herd. Twelve cows constitute the herd in Practices II and III when default values are used. The quantity of milk being considered is, therefore, 90 L per milking. Milk from each milking is considered separately. Process functions act upon milk-associated pathogens during the time from milking to the end of the defined storage periods. The calculation is performed on the pathogen population of the MILK compartment every hour starting 8 hr after grazing begins (the actual time depends on the class of sludge treatment, as specified by the U.S. EPA Pathogen Reduction Requirements (U.S. EPA, 1989b)). Raw milk in commercial production practices is stored, pasteurized and stored again before being drunk. However, to simulate a greater likelihood of infection, the model assumes that the milk is not pasteurized. Pathogen content is computed by Subroutine MILK for each hour, and a daily consumption of 2.0 kg is assumed (three time the national average reported in the FDA FY78 Total Diet Studies (U.S. FDA, 1978)).

3.2.3.1. PRE-PROCESSING STORAGE. The user may specify both the duration (variable TMIS2) and temperature (variable TEMI2) of raw milk storage. Default values are 24 hours for TMIS2 and 4°C for TEMI2 (variables used in this exposure risk calculation are listed in Table A-4). The RHO values for storage are:

Salmonella:	0.0/hour, for TEMI2 <4
	0.076/hour, up to a maximum of 1∗109 Salmonella/L for 4 ≤ TEMI2 ≤45 (Morris et al., 1979)
	-3.45/hour, for TEMI2 >45 (Brandon and Neuhauser, 1978; Wiley and Westerberg, 1969)
Ascaris:	0.0/hour, for TEMI2 <40
	-1.54/hour, for TEMI2 ≥40 (Brandon, 1978; Stern, 1974)
Enteroviruses:	0.0/hour, for TEMI2 <45
	-0.38/hour, for TEMI2 ≥45 (Ward et al., 1976; Younger, 1956)

The user may eliminate the effects of storage from the risk calculation by reducing storage duration to zero.

3.2.3.2. PASTEURIZATION. It is assumed that milk produced commercially for human consumption will be pasteurized. Pasteurization is a rapid heating of a thin layer of milk to 71-77°C for 15 seconds. This treatment is designed to reduce the normal bacterial flora of whole milk and eliminate vegetative pathogens. In these calculations, the number of Salmonella present (variable PASTB) will be reduced by 9 orders of magnitude (Brownlie, 1976; Jay, 1978), the number of Ascaris (variable PASTA) by 3 orders of magnitude (Cram, 1943) and the number of enteroviruses (PASTP) by 3 orders of magnitude (Sullivan et al., 1971) when the pasteurization option is used (IPAST=1). These are the default values listed in Table A-4. However, because the consumption of raw milk is modeled as a worst case, the program default value for IPAST is 0, which causes the program to skip the reduction in pathogen number due to pasteurization. The reduction of Ascaris and enteroviruses during pasteurization is not well characterized in the literature. Therefore, the user is encouraged to assign values to these variables as new information becomes available on the effect of pasteurization temperatures on Ascaris and enteroviruses. Note that the process function is not time dependent but is a single reduction in total population.

3.2.3.3. POST-PROCESSING STORAGE. After pasteurization, milk would again be stored, usually in a home refrigerator. The user may specify the duration (variable TMIS4) and temperature (variable TEMI4) of this second storage step. The default values for TMIS4 and TEMI4 are the same as for the corresponding variables in the earlier storage step, 24 hours and 4°C. Process functions during this storage are the same as for raw milk storage and are listed above.

3.3. VARIABLES AND DEFAULT VALUES FOR SUBROUTINE RAINS

Variables for operation of Subroutine RAINS are declared and given their default values by DATA statements in Subroutine RAINS. A subsequent menu allows the user to substitute alternative values for these variables. The variables are summarized in Table A-5 and described in more detail below.

Position	Name	Usage
2	PDUR	Duration of rainfall. Used to set the duration in hours of the rainfall event being modeled. The default value is 2 hours.
3	PTOT	Total rainfall. Used to set the amount in cm of rainfall in the current rainfall event. The default value is 5 cm, which represents a 5-year 1-hour rainfall event for most of the agricultural region of the United States (U.S. EPA, 1989a).
4	BTLAG	Basin time lag (hr). Represents the time difference between the centroid of the precipitation pulse and the peak of the runoff hydrograph. The default value is 0.5 hr. The user is encouraged to enter a number appropriate for the site being

modeled, as indicated by local hydrologic conditions (see Appendix B for further discussion).

5 CN

Curve number. A lumped measure of soil and cover characteristics of the watershed. Used to determine the total maximum retention parameter S:

$$S = 2.54[(1000/CN)-10]$$

The default value is 80. Details for choosing a value of CN appropriate to the land use practice and type and hydrologic condition of the soil are given in Appendix B and Soil Conservation Service (1972).

6 AMC

Antecedent moisture conditions. CN is dependent on the previous soil moisture level and must be modified if the soil was either wet or very dry before the rainfall. AMC is a flag for dry (1), neutral (2) or wet (3) antecedent conditions. The curve number CN is adjusted by the computer program if either wet or dry antecedent moisture conditions are specified. The default value of AMC is 2, indicating a range of 3.5-5.3 cm of precipitation during the previous 5 days (during the growing season). Details on choosing the value of AMC are given in the following table (Soil Conservation Service, 1972) and in Appendix B:

	Total 5-Day Antecedent Rainfall (cm)	
AMC Group	Dormant Season	Growing Season
1	< 1.3	< 3.5
2	1.3 - 2.8	3.5 - 5.3
3	> 2.8	> 5.3

7 STAD

Storm advancement coefficient. Represents the shape of the precipitation intensity curve, simplified so the storm is represented as building linearly in intensity to a peak and abating linearly in intensity. STAD is a measure of the fraction of the total duration of the storm at which the peak occurs. The default value of this parameter is 0.4. The user is encouraged to enter a value appropriate to the site being modeled. Details for choosing an appropriate value of STAD based on local weather conditions can be found in Chow et al. (1988) and in Appendix B.

8 USLEK

USLE K value (soil erodibility factor). A measure of average soil loss per unit area, a function of soil composition and structure. The default value of this parameter is 0.4. The user is encouraged to enter a value appropriate to the site being modeled (see Appendix B).

9 USLEL

USLE L value (slope length factor). Represents the relation of soil erosion to slope length. The default value of this

		parameter is 3.0. The user is encouraged to enter a value appropriate to the site being modeled (see Simons et al., 1982 and Appendix B): $L = (l/22.1)^m$ where: l = actual slope length in meters and m = 0.3 for slope <3%, 0.4 for slope of 3%-5% and 0.5 for slope >5%.
10	USLES	USLE S value (slope steepness factor). Represents the effect of slope on the ability of water to detach and transport sediment. The default value of this parameter is 0.25. The user is encouraged to enter a value appropriate to the site being modeled (see Appendix B).
11	USLEC	USLE C value (cover management factor). Represents the contribution of ground cover to resistance of the soil to erosion. The default value of this parameter is 0.5. The user is encouraged to enter a value appropriate to the site being modeled (see Appendix B).
12	USLEP	USLE P value (supporting practices). Represents the contribution of conservation measures to decreased erosion. The default value of this parameter is 1.0 for straight row farming. The user is encouraged to enter a value appropriate to the site being modeled. Details for choosing an appropriate value of USLEP based on land slope and farming practices are given in American Society of Civil Engineers (1977) and in Appendix B.
13	PI	Pathogen suspension factor. The ratio of soil pathogens suspended in water when the soil containing the pathogens is soaked with or suspended in water. The default condition sets this parameter equal to SUSPND [variable P(45)].
14	WSOIL	Bulk density of soil (g/cm^3). Used to convert volume of soil lost by sediment transport to mass. Default value is 1.33 g/cm^3 (U.S. EPA, 1989a). A description of variation of soil bulk density with soil composition can be found in U.S. EPA (1989a).

3.4. VARIABLES AND DEFAULT VALUES FOR SUBROUTINE GRDWTR

Variables used by Subroutine GRDWTR are declared in the subroutine. They are then set equal to variables P(102)-P(113). Menu positions and default values of the variables used in Subroutine GRDWTR are summarized in Table A-6 and described in more detail below.

Position	Name	Usage
	CA	Initial number of organisms entering the subroutine. This value is computed at the time the subroutine is called as CA4 = N(9) = FRGRND*N(8), the fraction of SUBSURFACE SOIL pathogens entering the groundwater compartment.
2	V	Velocity of groundwater (cm/hr) [P(103)]. Velocity of bulk groundwater flow between the application site and the groundwater well. This variable is dependent on hydraulic conductivity (related to soil composition and structure) and on hydraulic gradient; however, in this model the velocity of groundwater flow is defined to be constant. The default value is 3.6 cm/hr, representing silty sand and some average hydraulic gradient.
3	D	Hydrodynamic dispersion coefficient (cm^2/hr) [P(104)]. A measure of the spread of the slug of pathogens as it moves through the soil. This variable is dependent on groundwater velocity and dispersiveness (related to soil pore structure). Few studies are available to describe dispersion coefficients for bacteria in soil. A high dispersion coefficient would make the plume of contamination large, whereas a small dispersion coefficient would result in a higher concentration of pathogens in the plume. Therefore, it is difficult to choose a conservative value; the default value (60 cm^2/hr) is typical of chemicals in soil.
4	R	Retardation coefficient [P(105)]. Ratio of velocity of bulk water flow to velocity of the contaminant front. Because of electrostatic or chemical interactions between microbes and soil particles, R may be greater than 1. However, large particles may be restricted to large channels where the flow velocity is larger than the mean bulk flow velocity, so R may be less than 1. Reported values of R are as low as 0.5 for viruses (Grondin and Gerba, 1986) and 0.75 for enteric bacteria (Matthess et al., 1988). The default value is 1.0.
5	DZERO	Zero-order rate constant [P(106)] for increase in number of pathogens in groundwater after release from the sludge source. The default value is 0, because it is assumed that the pathogens do not grow in groundwater.
6	DONE	First-order rate coefficient for decay of input [P(107)], in hr^{-1}. The default value is 0.
7	DBND	Variable for decaying input concentration [P(108)], in hr^{-1}. The default value is 0.
8	ALPHA	Exponential rate constant [P(109)], in hr^{-1}, for inactivation of pathogens in water. If the user has changed PROC3, ALPHA should be changed to the same value. The default value is

		0.012/hr, representing inactivation of Salmonella or enterovirus. For Ascaris a value of $5.3 \bullet 10^{-4}$ is suggested.
9	XI	Starting distance (meters) from source [P(110)]. Distance from the source of contamination for which computations and output data begin. For a single exposure site (one groundwater well), XI = XM. The default value is 50 m.
10	DX	Distance increment (meters) in calculation [P(111)]. Amount by which the distance is increased at each iteration of the subsurface transport computation. As a result of a model run with XI < XM and DX < (XM-XI), a series of output tables will be printed in file EXOUT. Because time is incremented in a do-loop nested within the distance do-loop, each output will contain the incremented value of X with time as a variable. The default value of DX is 50 m.
11	XM	Maximum distance (meters) from source [P(112)]. Location of the groundwater well in a straight line from the source of contamination. If the well intake were at a depth of 30 m, a well located at a distance of 40 m from the point source of contamination would have a value XM = 50 m. The default value of XM is 50 m.
12	DT	Time increment (hr) in calculation [P(113)]. Amount by which the time is incremented at each iteration of the subsurface transport computation. The default value of DT is 1 hr.

4. OPERATION OF THE MODEL

Operation of the model is governed by a series of compartment differential equations, transfer factors and process functions. Transfers may occur hourly or at specified times only. The following sections describe the differential equations (Section 4.1), transfer factors (Section 4.2), transfer times (Section 4.3), and process functions (Section 4.4).

4.1. COMPARTMENT DIFFERENTIAL EQUATIONS

During each iteration of the model, PROGRAM MODEL calls Subroutine EVAL, which in turn calls the practice-specific subroutines to calculate the appropriate transfer factors (TRxy) and process functions (RHOn). Transfers and process-related changes are combined by Subroutine EVAL in a series of differential equations for NP(i), one for each compartment of the practice. PROGRAM MODEL then computes the new population N(i) of each compartment (i) by using the equation N(i) = N(i)+NP(i).

The compartment differential equations are listed below:

Practice 1.

```
NP(1) = TR01 - TR12 - TR18 + RHO1
NP(2) = TR12 -TR23 - TR24 + RHO2
NP(3) = RHO3
NP(4) = TR24 + TR114 + TR144 - TR43 - TR45 - TR46 - TR47
        - TR48 - TR411 - TR414 + RHO4
NP(5) = RHO5
NP(6) = TR46 + RHO6
NP(7) = TR47 + RHO7
NP(8) = TR18 + TR48 - TR89 - TR814 + RHO8
NP(9) = TR89 + RHO9
NP(10) = TR910 - TR1011 - TR1014 + RHO10
NP(11) = TR411 + TR1011 + TR1411 - TR114 - TR1114 + RHO11
NP(12) = RHO12
NP(13) = RHO13
NP(14) = TR414 + TR814 + TR1014 + TR1114 - TR144 - TR1411
         - TR1415 + RHO14
NP(15) = TR1415 - TR1516 + RHO15
NP(16) = TR1516 + RHO16
```

Practice 2.

```
NP(1) = TR01 - TR14 - TR18 - TR114 + RHO1
NP(3) = RHO3
NP(4) = TR14 + TR1104 + TR144 + TR194 - TR45 - TR46 - TR47
        - TR48 - TR411 - TR414 - TR417 + RHO4
```

```
NP(5) = RHO5
NP(6) = TR46 - TR617 + RHO6
NP(7) = RHO7
NP(8) = TR18 + TR48 - TR89 + RHO8
NP(9) = TR89 + RHO9
NP(10) = TR910 - TR1011 - TR1013 - TR1014 + RHO10
NP(11) = TR411 + TR1011 + TR1411 - TR1104 - TR1114 + RHO11
NP(12) = RHO12
NP(13) = RHO13
NP(14) = TR114 + TR414 + TR1014 + TR1114 - TR144
         - TR147 - TR1411 - TR1417 + RHO14
NP(17) = RHO17
NP(18) = TR1718 + TR2118 + RHO18
NP(19) = TR1719 - TR194 - TR1914 - TR1921 - TR1922 + RHO19
NP(20) = TR1720 + TR2220 + RHO20
NP(21) = TR1921 - TR2118 + RHO21
NP(22) = TR1922 - TR2220 + RHO22
```

Practice 3.

```
NP(1) = TR01 - TR13 -TR14 - TR18 - TR114 + RHO1
NP(3) = RHO3
NP(4) = TR14 + TR1104 + TR144 - TR45 - TR46 - TR47
        - TR48 - TR411 - TR414 + RHO4
NP(5) = RHO5
NP(6) = TR46 + RHO6
NP(7) = RHO7
NP(8) = TR18 + TR48 - TR89 + RHO8
NP(9) = TR89 + RHO9
NP(10) = TR910 - TR1011 - TR1013 - TR1014 + RHO10
NP(11) = TR411 + TR1011 + TR1411 - TR1104 - TR1114 + RHO11
NP(12) = TR912 + RHO12
NP(13) = TR1013 + RHO13
NP(14) = TR114 + TR414 + TR1014 + TR1114 - TR144
         - TR147 - TR1411 - TR1415 + RHO14
NP(15) = TR1415 -TR1517 + RHO15
NP(17) = TR1517 - TR1718 - TR1719 - TR1720 + RHO17
NP(18) = TR1718 + TR2118 + RHO18
NP(19) = TR1719 - TR1921 - TR1922 + RHO19
NP(20) = TR1720 + TR2220 + RHO20
NP(21) = TR1921 - TR2118 + RHO21
NP(22) = TR1922 - TR2220 + RHO22
```

Practice 4.

```
NP(1) = TR01 - TR12 - TR13 + RHO1
NP(2) = TR12 - TR23 - TR24 + RHO2
NP(3) = RHO3
NP(4) = TR24 + TR1104 + TR144 - TR43 - TR45 - TR47
        - TR48 - TR411 - TR414 + RHO4
NP(5) = RHO5
NP(7) = RHO7
```

NP(8) = TR48 - TR814 + RHO8
NP(11) = TR411 + TR1411 - TR1104 - TR1114 + RHO11
NP(14) = TR414 + TR814 + TR1114 - TR144
- TR147 - TR1411 - TR1415 + RHO14
NP(15) = TR1415 -TR1516 + RHO15
NP(16) = TR1516 + RHO16

Practice 5.

NP(1) = TR01 - TR12 - TR13 + RHO1
NP(2) = TR12 - TR23 - TR24 + RHO2
NP(3) = RHO3
NP(4) = TR24 + TR1104 + TR144 - TR45 - TR47 - TR48
- TR411 - TR414 + RHO4
NP(5) = RHO5
NP(7) = RHO7
NP(8) = TR48 + RHO8
NP(11) = TR411 + TR1411 - TR1104 - TR1114 + RHO11
NP(14) = TR414 + TR1114 - TR144 - TR147 - TR1411 + RHO14

4.2. TRANSFER FACTORS

Transfer factors describe the movement of organisms from one compartment to another at intervals (usually hourly) during the model run. Transfers may be conditional on a particular application option such as spray irrigation with liquid sludge, on time after initiation of the practice or on physical processes (e.g., a dust storm is not allowed when it is raining). Transfer functions for the five practices are summarized in Table A-7 and described in more detail below.

Transfer	Description
TR01	The entire pathogen load [ASCIN, P(3)] is transferred to Compartment 1, APPLICATION, at the beginning of the practice.
TR12	Except for a trivial amount which is lost as a liquid droplet aerosol generated during spray application, the entire contents of Compartment 1 are transferred to Compartment 2, INCORPORATION, in Practices I (spray application option), IV and V.
TR13	Liquid droplet aerosols can be generated by spray application of liquid sludge in Practices I, II and III. The number of pathogens released into the air per hour is given by the equation $TR13 = AEREFF*(5*10^3)*IRRATE*ASCIN/APRATE$ pathogens/hr where: AEREFF = efficiency of aerosol formation [P(31)]

$5*10^3$ = (1000 kg/m^3)*(5% sludge solids)*(10000 m^2/ha)*(.01 m/cm)
IRRATE = rate of irrigation ((cm/hr)*ha) [P(20)]
ASCIN = total pathogen load (pathogens/ha) [P(3)]
APRATE = application rate of sludge (kg/ha) [P(2)].

In Practices IV and V, particles of dry composted sludge may be suspended in the air by application and incorporation processes. The concentration of these particulates is estimated at 15 mg/m^3, a rate similar to that observed at compost preparation sites (Clark et al., 1983). It is assumed as a worst case that the particulates will remain over the area of application in a cloud 2 m high and that the rate of spreading of composted sludge is 0.01 ha/hr. Therefore, the transfer factor is calculated as

$$\begin{aligned} TR13 &= (15\ \mathrm{mg/m^3})*(10^{-6}\ \mathrm{kg/mg})*(2\ \mathrm{m\ height})*(10^4\ \mathrm{m^2/ha})*(0.01\ \mathrm{ha/hr}) \\ &\quad *(\mathrm{ASCRS\ pathogens/kg}) \\ &= (0.003)*(\mathrm{ASCRS\ pathogens/hr}). \end{aligned}$$

TR14 In Practices II and III the sludge is distributed by spray application between SOIL SURFACE (Compartment 4) and CROP SURFACE (Compartment 8). The fraction reaching SOIL SURFACE is given by the variable ASLSUR [P(41)], so TR14 = ASLSUR*N(1).

TR18 When the subsurface injection option is used, the fraction of sludge reaching SUBSURFACE SOIL is given by the variable FSSUR [P(42)]. Therefore, TR18 = FSSUR*N(1).

TR114 When the spray application option is used (Practices II and III), the fraction of sludge reaching CROP SURFACE is (1-ASLSUR) [ASLSUR = P(41)]. Therefore, TR114 = (1-ASLSUR)*N(1).

TR23 Incorporation of sludge would not occur in Practices II and III, in which sludge is applied to a growing crop, so there are no transfers from Compartment 2 in these practices. In Practice I, emissions are generated during incorporation by tilling equipment. The amount of sludge released as the particulate cloud during incorporation is given by an equation describing tilling with a disc, land plane or sweep plow (U.S. EPA, 1983a):

$$TR23 = ASCIN*6.04*EPSMLT*(ESILT^{0.6})/(2.0*10^6)$$

where:

ASCIN = total number of pathogens applied [P(3)]
6.04 = constant of the emissions equation
EPSMLT = particle size multiplier (dimensionless) [P(26)]
ESILT = fractional silt content of soil [P(27)]
$2*10^6$ = dilution factor for sludge mixed with surface soil.

It is assumed that composted sludge will be incorporated by use of a power tiller in Practices IV and V. The concentration of dust generated is again assumed to be 15 mg/m^3, and tilling is assumed to proceed at a rate of 0.005 ha/hr. For these practices,

$$TR23 = (15\ mg/m^3)*(0.005\ ha/hr)*(2\ m\ height)*(10^4\ m^2/ha)*(10^{-6}\ kg/mg)$$
$$*(ASCRS\ pathogens/kg)$$
$$= (0.0015)*(ASCRS\ pathogens/hr).$$

TR24 Incorporation of sludge would not occur in Practices II and III, in which sludge is applied to a growing crop, so there are no transfers from Compartment 2 in these practices. In Practices I, IV and V, as a result of the incorporation process, the remainder of the sludge pathogens associated with Compartment 2, INCORPORATION, are transferred to Compartment 4, SOIL SURFACE: TR24 = N(2).

TR43 Tilling emissions are assumed to be generated by cultivation of crops in Practices I and IV. No cultivation of cover crops is expected in Practices II, III and V. The number of pathogens released by cultivation is:

$$TR43 = N(4)*6.04*EPSMLT*(ESILT^{0.6})/(2.0*10^6)$$

where:

6.04 = constant of the emissions equation
EPSMLT = particle size multiplier (dimensionless) [P(26)]
ESILT = fractional silt content of soil [P(27)]
$2*10^6$ = dilution factor for sludge mixed with surface soil.

TR45 Pathogens from the SOIL SURFACE are transferred to particulates in all five practices by a wind storm. The transfer is described by a wind erosion equation (Gillette, 1981; U.S. EPA, 1985):

$$TR45 = (0.036)*(1.91)*(1\text{-}COVER)*((WINDSP/SCRIT)^3)*N(4)/(2*10^5)$$

where:

0.036 = constant of the equation
X = (0.886)*(SCRIT/WINDSP)
1.91 = limit value of empirical function F(X)
COVER = fraction of SOIL SURFACE with vegetation cover [P(30)]
SCRIT = threshold value of wind speed in m/sec, corrected or a height of 7 m [P(29)]
WINDSP = mean wind speed in m/sec [P(25)]
$2*10^5$ = $(2*10^6$ kg/ha of soil$)*(10^3$ g/kg$)/(10^4$ m^2/ha$)$.

TR46 The transfer of SOIL SURFACE pathogens to SURFACE RUNOFF is the product of the SOIL SURFACE population N(4) and the variable FRRAIN [P(43)]. Each hour after rainfall begins FRRAIN is assigned a value calculated by Subroutine RAINS and stored as an array.

TR47 In all five practices the transfer of pathogens from SOIL SURFACE to DIRECT CONTACT is given by the product of a soil ingestion rate in g/day and the concentration of pathogens in the SOIL SURFACE, adjusted by the required conversion factors:

$$TR47 = DRECTS*(1*10^{-3}\ kg/g)*N(4)/((2*10^{6}\ kg\ soil/ha)*(24\ hr/day))$$

where DRECTS = variable 5 in Subroutine RISK.

TR48 In all five practices the transfer of pathogens from SOIL SURFACE to SUBSURFACE SOIL is described by the equation TR48 = SUBSOL*N(4) where SUBSOL = [P(44)].

TR411 Similarly, the transfer of pathogens from SOIL SURFACE to SOIL SURFACE WATER is described by the equation TR411 = SUSPND*N(4) where SUSPND = [P(45)].

TR414 The transfer of pathogens from SOIL SURFACE to CROP SURFACE varies with the practice because of the variation in type and number of crops among the practices.

Practice I: TR414 = FCROPn*N(4), n being the crop designator 1 [aboveground crop, P(46)], 2 [on-ground crop, P(47)] or 3 [below-ground crop, P(48)].

Practices II, III and V: TR414 = SSTCS*N(4)/24, SSTCS being a daily transfer coefficient [P(57)].

Practice IV: Because a mixture of crops is used in this practice, the transfer function is described by the equation

$$TR414 = N(4)*[(FCROP1*PLNT1)+(FCROP2*PLNT2) + (FCROP3*PLNT3)]$$

where:
FCROP1 = P(46)
PLNT1 = P(74)
FCROP2 = P(47)
PLNT2 = P(75)
FCROP3 = P(48)
PLNT3 = P(76).

TR417 Transfer of pathogens from SOIL SURFACE to Compartment 17, ANIMAL CONSUMPTION, can occur in Practice II if cattle ingest soil as they graze. The total transfer is given by the product of the amount of soil ingested per cow, the number of cows, and the concentration of pathogens in the soil:

$$TR415 = SCNSMP*COWS*N(4)/(2*10^{6}\ g\ soil/ha)$$

where:
SCNSMP = P(83)
COWS = P(79).

TR617 Transfer of pathogens from SURFACE RUNOFF to ANIMAL CONSUMPTION occurs when cattle drink from the runoff pond in

Practice II. The total number of pathogens transferred is the product of the number of cattle, the number of pathogens in the SURFACE RUNOFF compartment, and the fraction of the pond ingested by each animal. It is assumed that each animal drinks 20 L of water daily from the pond. The transfer is calculated once for each day as

TR617 = (0.02*COWS*N(6))/VOLPND

where:
0.02 = water drunk per animal per day (m^3)
COWS = number of cattle/ha [P(79)]
VOLPND = volume of the runoff pond (m^3/ha) (variable 31 of Subroutine RISK)

TR89 Pathogens are transferred to GROUNDWATER by leaching from SUBSURFACE SOIL. The transfer is described as a simple fractional transfer:

TR89 = FRGRND*N(8), where FRGRND = P(53).

GROUNDWATER is not considered in Practices IV and V.

TR814 Pathogens in the SUBSURFACE SOIL may be transferred to the roots of plants grown in the contaminated soil in Practices I and IV. This transfer is of concern only in the case of below-ground crops. The transfer is described as:

TR814 = FCROP7*N(8) (Practice I) or
TR814 = FCROP7*PLNT3*N(8) (Practice IV)

where:
FCROP7 = P(52)
PLNT3 = P(76)

TR910 The entire contents of the GROUNDWATER compartment are considered to be available for use as IRRIGATION WATER in Practices I, II and III. Therefore, the transfer is given as TR910 = N(9). Groundwater is not considered in Practices IV and V.

TR912 The transfer of pathogens from GROUNDWATER to an OFFSITE WELL is computed by Subroutine GRDWTR, which is described in more detail in Section 5.4 below. The transfer is made as a daily average representing the output of the subroutine assuming a point source of pathogens equal to the number in one hectare. The transfer equation is TR912 = FLUX(DAY). Groundwater is not considered in Practices IV and V.

TR1011 The transfer of pathogens from IRRIGATION WATER to SOIL SURFACE WATER occurs in Practices I, II and III when the field is irrigated. If there is no crop present or if spread-flow irrigation is used, the entire number of pathogens in the irrigation water is transferred to the SOIL SURFACE WATER. However, if there is a crop present and spray irrigation is used, a portion (assumed to be 10%) of the pathogens will adhere to the CROP SURFACE. There is also no transfer of pathogens from IRRIGATION WATER to below-ground crops. Therefore, these transfers are conditional on variables IRMETH [P(17)], CROP [P(66)] and TCROP [P(68)]. It is assumed that some pathogens will be lost during spray irrigation as a liquid droplet aerosol. The transfer is described as:

TR1011 = (1-AEREFF)*SOURCE if no crop is present, or
TR1011 = 0.9*(1-AEREFF)*SOURCE if a crop is present

where:
AEREFF = P(31)
SOURCE = ((1-DILIRR)*N(10)*IRRATE/(100*AQUIFR*POROS)) + (DILIRR*COUNT*(IRRATE*($5*10^3$))

In the latter equation, DILIRR [P(18)] is the amount of dilution of contaminated groundwater by liquid sludge used as a secondary source of irrigation water; IRRATE [P(20)] is the rate of irrigation in cm/hr; AQUIFR [P(9)] is the thickness (m) of the aquifer and POROS [P(10)] is the porosity of the aquifer, so that IRRATE/(100*AQUIFR*POROS) is the fraction of the aquifer represented by the new amount of IRRIGATION WATER; and COUNT [P(22)] is the pathogen concentration in pathogens/kg in the secondary source. $5*10^3$ is a conversion factor that includes the assumption that the concentration of sludge solids in the secondary irrigation source is 5%:

$$(5*10^{-2}\ \mathrm{kg/L})*(10^8\ \mathrm{cm^2/ha})*(10^{-3}\ \mathrm{L/cm^3}) = 5*10^3\ \mathrm{kg/cm/ha}.$$

TR1013 The fraction of sludge pathogens escaping as a liquid droplet aerosol when liquid sludge or contaminated IRRIGATION WATER is applied is given by the variable AEREFF [P(31)], so TR1013 = AEREFF*SOURCE.

TR1014 Some of the pathogens in IRRIGATION WATER adhere to the CROP SURFACE during spray irrigation. This fraction is assumed to be 10% of the number of pathogens in the irrigation spray:

TR1014 = 0.1*(1-AEREFF)*SOURCE.

TR1104 Most of the pathogens in the SOIL SURFACE WATER return to SOIL SURFACE as the water soaks in. The only other receiving compartment for SOIL SURFACE WATER pathogens is CROP SURFACE. Therefore, TR1104 = N(11)-TR1114.

TR1114 The fraction of SOIL SURFACE WATER pathogens transferred to the CROP SURFACE varies with the practice being modeled:

Practice I: TR1114 = FCROPn*N(11)
where:
FCROPn = crop-specific fraction of SOIL SURFACE WATER pathogens transferred to CROP SURFACE
n = 4 for crop 1 [aboveground crop, P(49)]
n = 5 for crop 0 [on-ground crop, P(50)].

Pathogens in SOIL SURFACE WATER do not come in contact with below-ground crops.

Practices II, III and V: $TR1114 = SSWTCS * N(11)$,
where $SSWTCS = P(54)$.

Practice IV: $TR1114 = N(11)*((FCROP4*PLNT1)+(FCROP5*PLNT2))$

where:
FCROP4 = transfer factor: soil surface water to aboveground crop [P(49)]
PLNT1 = fraction of crop represented by aboveground crop [P(74)]
FCROP5 = transfer factor: soil surface water to on-ground crop [P(50)]
PLNT2 = fraction of crop represented by on-ground crop [P(75)].

TR144 The transfer of pathogens from CROP SURFACE to SOIL SURFACE represents contaminated dust falling back to the ground. It is estimated that in Practice I 20% of the CROP SURFACE contaminants will be transferred at a constant rate over a period of 5 days, so the hourly transfer is:

$$TR144 = 0.0016667*N(14).$$

In Practice IV, this value is corrected for the fraction of CROP SURFACE represented by below-ground crop:

$$TR144 = 0.0016667*N(14)*(1-PLNT3),$$

where PLNT3 is the fraction of crop represented by below-ground crop [P(76)].

In Practices II, III and V, a user-designated fraction of CROP SURFACE pathogens are transferred to SOIL SURFACE:

$$TR144 = (CSTSS/24)*N(14),$$

where CSTSS is the fraction of CROP SURFACE pathogens transferred daily to the SOIL SURFACE [P(56)].

TR147 In all five practices, the transfer of pathogens from CROP SURFACE to DIRECT CONTACT is given by the product of the crop surface ingestion rate in g/day and the concentration of pathogens in the CROP SURFACE, adjusted by the required conversion factors (the amount of CROP SURFACE is estimated to be 1.6 kg/m^2 (Whittaker, 1975)):

$$TR147 = DRECTC*(1*10^{-3})*N(14)/((1.6*10^{4})*24)$$

where:
DRECTC = direct exposure to crop (g/day) (variable 31 in

Subroutine RISK)
$1 \cdot 10^{-3}$ = conversion factor, kg/g
$1.6 \cdot 10^{4}$ = kg crop/ha
24 = conversion factor, hr/day.

In addition, there is a transfer of CROP SURFACE pathogens to DIRECT CONTACT in Practice V when the grass is mowed. This transfer is assumed to occur weekly after the grass has had time to grow (960 hours) and when the weather is warm enough for mowing to be required (TEMP > 18). It is assumed that 26 mowings per year will be required and that the annual yield of grass is 1.6 $\mathrm{kg/m^2}$ (Whittaker, 1975):

$$\mathrm{TR147} = \mathrm{DRECTC} \cdot \mathrm{PSTMG} \cdot N(14)/((1.6 \cdot 10^{4}\ \text{kg grass/ha}) \cdot (26\ \text{mowings/yr}))$$

where PSTMG [P(55)] is the fraction of grass removed by mowing. The pathogens transferred to DIRECT CONTACT after mowing are assumed to be removed from the practice because they will be disposed of in some way.

TR1411 The transfer of pathogens from CROP SURFACE to SOIL SURFACE WATER is assumed to be a constant fraction CSTSSW [P(58)] of the CROP SURFACE population:

$$\mathrm{TR1411} = \mathrm{CSTSSW} \cdot N(14).$$

In Practice IV, this fraction is corrected for the amount of CROP SURFACE in below-ground crops [PLNT3, P(76)]:

$$\mathrm{TR1411} = \mathrm{CSTSSW} \cdot N(14) \cdot (1-\mathrm{PLNT3}).$$

TR1415 When crops are harvested in Practices I, III and IV, all of the pathogens remaining in CROP SURFACE are transferred to HARVESTING:

$$\mathrm{TR1415} = N(14).$$

TR1417 In Practice II, crops are not harvested but are consumed directly by cattle. The number of pathogens transferred to ANIMAL CONSUMPTION is calculated once for each day, as the product of the number of cattle, the amount they eat daily, and the concentration of pathogens in the grass:

$$\mathrm{TR1417} = \mathrm{FORAG} \cdot \mathrm{COWS} \cdot N(14)/1.6 \cdot 10^{4}$$

where:
FORAG = kg forage consumed/day per animal [P(81)]
COWS = number of cattle/ha [P(79)]
$1.6 \cdot 10^{4}$ = kg grass/ha.

TR1516 HARVESTING serves as a transit compartment for all pathogens in the harvested crop to COMMERCIAL CROP (Practice I) or CROP (Practice IV):

TR1516 = N(15).

TR1517 In Practice III, harvested crops are fed to cattle, with the resulting transfer from HARVESTING to ANIMAL CONSUMPTION. This transfer is assumed to occur daily. The cattle are fed the harvested crop from the end of the storage time (LAG) for a number of days (FATTEN), or until the harvest is all consumed. The default yield of hay is 1.6 kg/m^2 (Whittaker, 1975).

$$TR1517 = FORAG \cdot COWS \cdot ALFALF \cdot N(15)/(HAY \cdot (1 \cdot 10^6))$$

where:

FORAG = forage consumed daily per cow (kg dry weight) [P(81)]
COWS = number of cattle supported per ha of forage [P(79)]
ALFALF = percent of forage provided by crop grown on sludge-amended soil [P(82)]
HAY = yield of hay or grass, kg/m^2 [P(73)]
$1 \cdot 10^4$ = conversion factor, $m^2/ha \cdot 100$ (% conversion).

TR1718 The number of Salmonella pathogens transferred from ANIMAL CONSUMPTION to MEAT is given by the variable DTCTMT [P(59)] in Practices II and III:

$$TR1718 = DTCTMT \cdot N(17).$$

It is assumed that human enteroviruses and Ascaris will not cause a systemic infection in cattle and therefore will not be transferred to meat.

TR1719 Transfer of pathogens from ANIMAL CONSUMPTION to MANURE is assumed to occur daily in Practices II and III, but only if the animals have ingested a number of Salmonella pathogens sufficient to cause disease (it is assumed that human enteroviruses and Ascaris do not cause disease in cattle). If that level has been achieved, it is assumed that the entire herd is infected and excretes pathogens at a rate of $4 \cdot 10^{12}$/day. The transfer continues for 5 days:

$$TR1719 = 4 \cdot 10^{12} \cdot COWS, \text{ where } COWS = P(79).$$

TR1720 The number of Salmonella pathogens transferred from ANIMAL CONSUMPTION to MILK is given by the variable DTCTMK [P(60)] in Practices II and III:

$$TR1720 = DTCTMK \cdot N(17).$$

It is assumed that human enteroviruses and Ascaris will not cause a systemic infection in cattle and therefore will not be transferred to milk.

TR194 Transfer of pathogens from MANURE to SOIL SURFACE occurs only in Practice II. This transfer occurs daily and is described by the equation

$$TR1904 = TMTSS \cdot N(19), \text{ where } TMTSS = P(61).$$

TR1914 Transfer of pathogens from MANURE to CROP SURFACE occurs only in Practice II. This transfer occurs daily and is described by the equation

$$\mathrm{TR1914} = (1-(\mathrm{TMTSS}+\mathrm{TMTH}+\mathrm{TMTU}))\cdot \mathrm{N}(19)$$

where:

TMTSS = transfer factor: MANURE to SOIL SURFACE [P(61)]
TMTH = transfer factor: MANURE to HIDE [P(62)]
TMTU = transfer factor: MANURE to UDDER [P(63)].

TR1921 Transfer of pathogens from MANURE to HIDE occurs only in Practices II and III. This transfer occurs daily and is described by the equation

$$\mathrm{TR1921} = \mathrm{TMTH}\cdot \mathrm{N}(19), \text{ where } \mathrm{TMTH} = \mathrm{P}(62).$$

TR1922 Transfer of pathogens from MANURE to UDDER occurs only in Practices II and III. This transfer occurs daily and is described by the equation

$$\mathrm{TR1922} = \mathrm{TMTU}\cdot \mathrm{N}(19) \text{ where } \mathrm{TMTU} = \mathrm{P}(63).$$

TR2118 Transfer of pathogens from HIDE to MEAT occurs only in Practices II and III. This transfer occurs once only, one hour after slaughter, and is described by the equation

$$\mathrm{TR2118} = \mathrm{HTM}\cdot \mathrm{N}(21), \text{ where } \mathrm{HTM} = \mathrm{P}(64).$$

TR2220 Transfer of pathogens from UDDER to MILK occurs only in Practices II and III. This transfer occurs daily and is described by the equation

$$\mathrm{TR2220} = \mathrm{UTM}\cdot \mathrm{N}(22), \text{ where } \mathrm{UTM} = \mathrm{P}(65).$$

4.3. TRANSFER TIMES

Transfer times depend on a number of factors, each appropriate to the source compartment. Transfers may occur once only, hourly, daily or only if certain conditions are met.

Special conditions are required to meet the Pathogen Reduction Requirements proposed by the U.S. EPA (1989b). Sludge processing is grouped in three classes, with a variety of options proposed to meet the standards of each class. Class A treatment must (1) reduce detectable levels of pathogens to or below 3 Salmonella, 1 virus, 1 protozoan and 1 helminth egg per gram volatile suspended sludge solids, or (2) include a heat treatment and reduce levels of both fecal coliforms and fecal streptococci to or below 100 per gram volatile suspended sludge solids. These treatments are assumed to render the sludge harmless with respect to microbial pathogens, so no waiting period is imposed.

Class B treatment must (1) reduce detectable levels of both Salmonella and viruses by a factor of at least 100 per gram volatile suspended sludge solids, or (2) include treatment by a physical, biological or chemical addition method or storage for at least one day and result in levels of not more than 10^6 fecal coliforms and not more than 10^6 fecal streptococci per gram volatile suspended sludge solids. The proposed waiting period for growing or harvesting crops depends on the type of crop.

Class C treatment must (1) reduce detectable levels of Salmonella and viruses by a factor of approximately 32, or (2) include processing steps that result in levels of not more than $2*10^6$ fecal coliforms and not more than $5*10^6$ fecal streptococci per gram volatile suspended sludge solids. The proposed waiting period for growing or harvesting crops depends on the type of crop.

Waiting period (months)

Treatment Class	Type of Crop to be Grown			
	Aboveground	On-ground	Below-ground	Forage
A	None	None	None	None
B	18	18	60*	1
C	18	18	60*	2

*18 months if no helminth ova are present in the sludge

Transfer times are described below and summarized in Table A-8.

Transfer	Description
TR01	All practices begin with a transfer of sludge into Compartment 1, APPLICATION, at 0 hours.
TR12	Transfers to Compartment 2, INCORPORATION, occur at times that depend on the sludge reuse practice. In Practice I, it is assumed that the field must be allowed to dry for 24 hours after application before tilling equipment can be brought in to incorporate the sludge. In Practices II and III, incorporation is not appropriate, because liquid sludge is applied to a standing crop. In Practices IV and V, application is assumed to proceed at a rate of 0.01 ha/hr, so the time at which incorporation can begin (the time at which TR12 occurs) is given by AREA/0.01 [AREA = P(7)].
TR13	In Practices I-III it is assumed that spray application will result in the production of liquid aerosol emissions (Compartment 3, APPLICATION EMISSIONS). These emissions are assumed to be generated hourly for the

first (DEPTH/IRRATE) hours of the practice. No APPLICATION EMISSIONS are assumed from spread-flow or injection application of liquid sludge. In Practices IV and V, it is assumed that a cloud of dust will be generated during application of the composted sludge. This dust cloud will exist during the entire application period, or up to AREA/0.01 hr, so TR13 occurs hourly until AREA/0.01 hr [AREA = P(7)].

TR14	Direct transfer of sludge from Compartment 1, APPLICATION, to Compartment 4, SOIL SURFACE, occurs only in Practices II and III. This transfer represents liquid sludge soaking into the upper 5 cm of SOIL SURFACE after application. It is assumed that this process will be complete by 15 hr; therefore TR14 occurs at 15 hr.
TR18	If APMETH [P(6)] = 0, liquid sludge is applied by subsurface injection. It is assumed that in all practices, transfer of sludge from Compartment 1, APPLICATION, to Compartment 8, SUBSURFACE SOIL, by injection application will be complete at 10 hr; TR18 occurs at 10 hr.
TR114	A portion of the sludge applied in Practices II and III by spray application goes directly from Compartment 1, APPLICATION, to Compartment 14, CROP SURFACE. It is assumed that this transfer is complete by 15 hr; TR114 occurs at 15 hr.
TR23	TILLING EMISSIONS are generated by tilling equipment engaged in incorporating sludge into the soil in Practices I, IV and V. It is assumed that incorporation proceeds as a rate of 5 ha/hr in Practice I and 0.005 ha/hr in Practices IV and V. The transfer from Compartment 2, INCORPORATION, to Compartment 3, TILLING EMISSIONS, begins at hour 24 and occurs hourly until (24+(AREA/5)) hr in Practice I [AREA = P(7)]. It begins at the beginning of INCORPORATION (AREA/0.01) and occurs hourly until (AREA/0.01)+(AREA/0.005) hr in Practices IV and V.
TR24	Transfer from Compartment 2, INCORPORATION, to Compartment 4, SOIL SURFACE, does not occur in Practices II and III. In Practice I, this transfer occurs at 24+(AREA/5) hr [AREA = P(7)], or 2 hr after tilling has been completed. In Practices IV and V, the transfer occurs at a time given by (AREA/0.01)+(AREA/0.005), the time required for application and tilling to be accomplished.
TR43	Particulate emissions are generated during cultivation of the SOIL SURFACE in Practices I and IV. Cultivation is not considered appropriate for Practices II, III and V, in which there is a cover crop. In the default condition (TCULT [P(67)] flag setting = -2), cultivation does not occur. If the user enters a value for TCULT as a variable, the transfer from Compartment 4, SOIL SURFACE, to Compartment 3, TILLING EMISSIONS, begins at that single time TCULT. In Practice I it occurs hourly until (TCULT+(AREA/5)) hr [AREA = P(7)], assuming a cultivation rate of 5 ha/hr, and in Practice IV it occurs until (TCULT+(AREA/0.005)) hr, assuming a cultivation rate of 0.005 ha/hr when cultivating by hand. Optionally, if TCULT=0, cultivation will occur biweekly, beginning at 336 hr into the practice, continuing for AREA/5 hr (Practice I) or AREA/0.005 hr (Practice IV). Cultivation ceases at

THARV [P(69)], because after that time it is assumed that there is no crop to require cultivation. Therefore, TR43 does not occur (TCULT=-2); occurs hourly from TCULT until (TCULT+(AREA/5)) or (TCULT+(AREA/0.005)) hr (TCULT = any integer up to TDONE); or occurs hourly from 336 hr to (336+(AREA/5)) or (336+(AREA/0.005)) hr, repeating the cycle every 336 hr thereafter (TCULT=0).

TR45 Soil particles are assumed to be removed from Compartment 4, SOIL SURFACE, by a windstorm whose beginning and duration are given by the variables TWIND [P(23)] and DWIND [P(24)], respectively. The transfer TR45 from Compartment 4, SOIL SURFACE, to Compartment 5, PARTICULATES, occurs hourly from TWIND hr until (TWIND+DWIND) hr. Conditional statements in the program prevent the transfer if the windstorm occurs during a period of rainfall or irrigation, when the soil is assumed to be too wet to be blown away by the wind.

TR46 Transfers from Compartment 4, SOIL SURFACE, to Compartment 6, SURFACE RUNOFF, occur hourly during each rainfall. The transfer is done in each EVAL subroutine when time = TRAIN [P(13)], a value which is taken from an array generated by Subroutine RAINS. The array contains an entry TRAINH(IRAIN) identifying each hour of each rainfall and the associated fractional transfers during that hour. The EVAL subroutine compares the time T with the time of the first transfer [TRAINH(1)] until it finds a match, at which time it calculates the associated transfer TR46. It then increments the subscript of the variable TRAINH(IRAIN) by 1. Thus no transfers occur during hours at which there was no rainfall. Because Compartment 6 is not used in Practices IV and V in which surface runoff is assumed to leave the site without contributing to human exposure, TR46 occurs only in Practices I, II and III.

TR47 In all practices transfers of pathogens from Compartment 4, SOIL SURFACE, to Compartment 7, DIRECT CONTACT, are assumed to occur hourly from the beginning of the practice. To calculate the exposure, it is necessary to know the concentration of pathogens in the SOIL SURFACE. Soil is assumed to have an average density of 1.33. The weight of soil per hectare in a SURFACE SOIL compartment in Sludge Management Practices I, IV and V is $2*10^6$ kg ((1 ha)*(15 cm deep)*(1.33 g/cm^3)). In Practices II and III, the weight of soil per hectare is $0.665*10^6$ kg ((1 ha)*(5 cm)*(1.33)). The concentration of pathogens comprising the human exposure by direct contact with and ingestion of soil is calculated by dividing the contents of the relevant compartment by the weight of soil in the compartment.

TR48 Transfers from Compartment 4, SOIL SURFACE, to Compartment 8, SUBSURFACE SOIL, occur in all five practices and are conditional on irrigation or rainfall, which supply enough water to leach the pathogens from the surface to the subsurface (defined as below 15 cm). The transfer occurs at a time after rainfall or irrigation that is calculated to be enough to allow infiltration of added water to the subsurface. As described above, TK [P(15)] and TIRRG [P(16)] are used as counters for the time since the beginning of the most recent rainfall and irrigation, respectively. After rainfall ($TK \leq TIRRG$) infiltration will be complete at (RDEPTH+15)/FILTR8 hr, where RDEPTH [P(14)] is the total amount of rainfall and FILTR8 [P(11)] is the rate of infiltration in cm/hr. Thus for rainfall, TR48 occurs when TK = (RDEPTH+15)/FILTR8. For irrigation ($TIRRG < TK$), the transfer time depends on whether infiltration or irrigation is faster. If the infiltration rate FILTR8 is less than the irrigation rate IRRATE [P(20)], the transfer will occur when TIRRG = (DEPTH+15)/FILTR8 where TIRRG is the elapsed time in hr since the beginning of that irrigation and DEPTH P(21)] is the total amount of irrigation in cm. If $IRRATE \leq FILTR8$, the transfer will occur when TIRRG = (DEPTH+15)/IRRATE.

TR411	Transfer of pathogens from Compartment 4, SOIL SURFACE, to Compartment 11, SOIL SURFACE WATER, occurs when rainfall or irrigation water suspends pathogens from the sludge in the surface water. This transfer is calculated to occur hourly during rain (T = TRAIN [P(13)]) or during irrigation (TIRRG = 0), where TIRRG [P(16)] is the elapsed time since the cessation of irrigation.
TR414	The transfer of pathogens from Compartment 4, SOIL SURFACE, to Compartment 14, CROP SURFACE, occurs when soil is lifted by the wind and deposited on the crop surface. In Practices I and IV this occurs only when aboveground crops are present (at TWIND [P(23)] > TCROP [P(68)]), whereas in Practices II and III aboveground crops are assumed to be present at all times and the transfer occurs hourly. In Practice V, the transfer occurs hourly after TCROP, the time at which a crop surface is present. In Practices I and IV, TR414 also occurs just before harvesting the crop, at (THARV-1) hr [THARV = P(69)].
TR417	In Practice II, transfers of pathogens from Compartment 4, SOIL SURFACE, to Compartment 17, ANIMAL CONSUMPTION, are assumed to occur hourly after the cattle begin to graze on the sludge-amended field and incidentally ingest some of the soil. This time is assumed to be 54 hr for Class A treated sludge, 745 hr (1 month (730 hr) after TR14 (15 hr)) for Class B treated sludge or 1475 hr (2 months (1460 hr) after TR14) for Class C treated sludge. These waiting periods are required by proposed U.S. EPA pathogen reduction regulations (U.S. EPA, 1989b).
TR617	Cattle grazed on the sludge-amended land are assumed to drink from the surface runoff pond in Practice II. This results in a transfer from Compartment 6, SURFACE RUNOFF, to Compartment 17, ANIMAL CONSUMPTION. The transfer is calculated once for each day beginning at 54 hr for Class A treated sludge, 745 hr (1 month after TR14) for Class B treated sludge or 1475 hr (2 months after TR14) for Class C treated sludge.
TR89	Transfers from Compartment 8, SUBSURFACE SOIL, to Compartment 9, GROUNDWATER, occur in Practices I-III and are conditional on irrigation or rainfall, which supply enough water to leach the pathogens from the surface to the subsurface (defined as below 15 cm) and thence to GROUNDWATER. The transfer occurs one hour after a time following rainfall or irrigation that is calculated to be enough to allow infiltration

of added water to the subsurface. As described above, TK [P(15)] and TIRRG [P(16)] are used as counters for the time since the beginning of the most recent rainfall and irrigation, respectively. After rainfall (TK $\leq$ TIRRG) infiltration will be complete at (RDEPTH+15)/FILTR8 hr, where RDEPTH [P(14)] is the total rainfall and FILTR8 [P(11)] is the rate of infiltration in cm/hr. Thus for rainfall, TR89 occurs when TK = ([(RDEPTH+15)/FILTR8]+1). For irrigation (TIRRG < TK), the transfer time depends on whether infiltration or irrigation is faster. If the infiltration rate FILTR8 < IRRATE [P(20)] (the irrigation rate), the transfer will occur when TIRRG = ([(DEPTH+15)/FILTR8]+1), where TIRRG is the elapsed time in hr since the beginning of that irrigation and DEPTH [P(21)] is the total amount of irrigation in cm. If IRRATE $\leq$ FILTR8, the transfer occurs when TIRRG = ([(DEPTH+15)/IRRATE]+1).

TR814	Transfer of pathogens from Compartment 8, SUBSURFACE SOIL, to Compartment 14, CROP SURFACE, occurs only in Practices I and IV, and only when below-ground crops are harvested. The transfer occurs at (THARV-1) hr [THARV = P(69)].
TR910	Transfers from Compartment 9, GROUNDWATER, to Compartment 10, IRRIGATION WATER, occur hourly in Practices I-III.
TR912	Transfers from Compartment 9, GROUNDWATER, to Compartment 12, OFFSITE WELL, occur in Practices I-III, once each day after the first call to Subroutine GRDWTR, which occurs at the time of the first transfer to groundwater (TR89). The value of TR912 is calculated as FLUX(IMAX) in Subroutine GRDWTR as a mean for the 24-hour period and saved in a direct-access file with one record for each day of the practice.
TR1011	Transfers from Compartment 10, IRRIGATION WATER, to Compartment 11, SOIL SURFACE WATER, represent irrigation water being applied to the surface of the field. These transfers occur hourly during irrigation in Practices I-III. The bounds of the transfer are set by a series of conditional statements in the EVAL subroutine: the time must be at least as great as the time specified for the transfer to SOIL SURFACE (T $\geq$ 24); at least 24 hr must have elapsed since the end of the most recent rainfall (TK [P(15)] $\geq$ 24); and irrigation does not occur during a wind storm (TWIND $\leq$ T $\leq$ (TWIND+DWIND)), where TWIND = P(23) and DWIND = P(24). If these conditions are met, irrigation occurs at intervals calculated by dividing 168 hr/wk by the variable NIRRIG [P(19)], number of irrigations per week and rounding to the next higher integer: NUMIRG = INT(168/NIRRIG). Whenever T=TRAIN [P(13)] the irrigation timer TIRRG and the rainfall timer TK are reset to 0. Otherwise TK is incremented hourly and TIRRG is made equal to the lesser of TK or the time since the last irrigation (TIRRG = MIN0(MOD(T-2,NUMIRG),TK)). This has the effect of substituting rainfall for irrigation, regardless of whether the amount of rainfall was as great as that of the preempted irrigation. The transfer TR1011 occurs during the period required for irrigation, when TIRRG is greater than 0 and less than the next larger integer of the quotient DEPTH/IRRATE, where DEPTH is a variable [P(21)] for the total depth in cm of irrigation and IRRATE is a variable

[P(20)] for the rate of irrigation in cm/hr.

TR1013 Similarly, transfers from Compartment 10, IRRIGATION WATER, to Compartment 13, IRRIGATION AEROSOLS, occur hourly during irrigation in Practices I-III. The bounds of this transfer are set in the same way as for the transfer TR1011, except that transfers occur only if spray irrigation is the method of application.

TR1014 Transfers from Compartment 10, IRRIGATION WATER, to Compartment 14, CROP SURFACE, occur hourly during irrigation in Practices I-III. The bounds of this transfer are set in the same way as for the transfer TR1011, except that no transfers occur if spray irrigation is not the method of application.

TR1104 Transfers of pathogens from Compartment 11, SOIL SURFACE WATER, to Compartment 4, SOIL SURFACE, occur at the end of each irrigation in all five practices. Transfer occurs when TIRRG [P(16)] equals the next larger integer than the quotient DEPTH/IRRATE, where DEPTH = P(21) and IRRATE = P(20).

TR1114 Transfers of pathogens from Compartment 11, SOIL SURFACE WATER, to Compartment 14, CROP SURFACE, occur at the end of each irrigation in all five practices, but only when a crop is present ($T \geq$ TCROP [P(68)]). Transfer occurs when TIRRG equals the next larger integer than the quotient DEPTH/IRRATE, where DEPTH = P(21) and IRRATE = [P(20)].

TR144 Pathogens are assumed to be deposited on the CROP SURFACE by the action of wind in Practices I, IV and V, whereas in Practices II and III wind erosion should be less significant because of the continuous presence of ground cover. In Practices I, IV and V the pathogens in Compartment 14, CROP SURFACE, are assumed to be transferred back to Compartment 4, SOIL SURFACE, at a constant hourly rate over a period of 5 days after the wind storm, from (TWIND+DWIND) hr to (TWIND+120) hr, where TWIND = P(23) and DWIND = P(24). In Practices II and III a fraction CSTSS/24 [CSTSS = P(56)] of the pathogens present on the CROP SURFACE is transferred hourly back to SOIL SURFACE.

TR147 Transfers of pathogens from Compartment 14, CROP SURFACE, to Compartment 7, DIRECT CONTACT, are made once for each day after the beginning of the transfers. Transfers begin after a crop is present ($T \geq$ TCROP [P(68)]) in Practices I, IV and V. In Practice I transfers cease when $T >$ THARV [P(69)]. In Practices II and III it is assumed that direct contact with the contaminated crop surface is delayed until 54 hr after application begins, so TR147 occurs when $T > 54$ hr. Transfers in Practices II-V continue until the end of the practice. In addition to the daily transfer, there is a transfer in Practice V each time the lawn is mowed, which occurs weekly while the temperature is above 18°C.

TR1411 Pathogens are assumed to be washed to Compartment 11, SOIL SURFACE, from Compartment 14, CROP SURFACE, of on-ground crops in Practices I and IV and from the surface of cover crops in Practices II, III and V. This transfer occurs at the beginning of each irrigation, when TIRRG

[P(16)] = 0.

TR1415 Transfer of pathogens from Compartment 14, CROP SURFACE, to Compartment 15, HARVESTING, occurs in Practices I, III and IV. In Practices I and III it is assumed for simplicity that the harvest occurs only once, whereas in Practice IV it was considered necessary to assume that the home gardener would harvest vegetables every day after they first become ripe. Therefore, for Practices I and III, TR1415 occurs only at THARV [P(69)], and for Practice IV, TR1415 occurs hourly after THARV. Harvesting occurs in Practice IV only if TEMP > 0.

TR1417 Transfer of pathogens from Compartment 14, CROP SURFACE, to Compartment 17, ANIMAL CONSUMPTION, occurs in Practice II instead of the transfer to HARVESTING. The transfer is made once each day after the cattle begin to graze the field (54 hr for Class A treated sludge, 745 hr (1 month after TR14) for Class B treated sludge or 1475 hr (2 months after TR14) for Class C treated sludge).

TR1516 Transfer of pathogens from Compartment 15, HARVESTING, to Compartment 16, COMMERCIAL CROP (Practice I) or CROP (Practice IV) occurs after a waiting period that represents the time lag between harvesting and the beginning of processing. In Practice I the lag is 24 hr, so TR1516 occurs at (THARV+24) hr. In Practice IV the lag should be less (assumed 5 hr), so the transfer occurs hourly after (THARV+5) hr until the end of the practice. Harvesting occurs in Practice IV only if TEMP > 0.

TR1517 Transfer of pathogens from Compartment 15, HARVESTING, to Compartment 17, ANIMAL CONSUMPTION, occurs in Practice III, in which the crop is stored for a time given by the variable STORAG [P(80)] before it is fed to the cattle. The transfer is made once each day after (THARV+STORAG) hr, where THARV = P(69) and STORAG = P(80).

TR1718 Transfer of pathogens from Compartment 17, ANIMAL CONSUMPTION, to Compartment 18, MEAT, occurs only in Practices II and III, only if the beef cattle option has been chosen and only if the cattle have ingested an infectious dose of Salmonella. It is assumed that 48 hours will elapse before septicemia develops from the infection and that septicemia will last an additional 120 hr. The transfer is made daily, starting 48 hr after the animals are first fed the crop, at (THARV+STORAG+48) hr for Practice III and, for Practice II, 102 hr for Class A treated sludge, 793 hr (1 month+48 hr after TR14) for Class B treated sludge or 1523 hr (2 months+48 hr after TR14) for Class C treated sludge.

TR1719 Transfer of pathogens from Compartment 17, ANIMAL CONSUMPTION, to Compartment 19, MANURE, occurs only in Practices II and III and only if the cattle have ingested an infectious dose of Salmonella. It is assumed that 12 hours will elapse before the bacteria begin to be shed in the manure and that shedding will continue for an additional 240 hr. The transfer is made once daily, starting 12 hr after the animals are first fed the crop, at (THARV+STORAG+12) hr for Practice III and, in Practice II, 66 hr for Class A treated sludge, 757 hr (1 month+12 hr after TR14) for

Class B treated sludge or 1487 hr (2 months+12 hr after TR14) for Class C treated sludge.

TR1720 Transfer of pathogens from Compartment 17, ANIMAL CONSUMPTION, to Compartment 20, MILK, occurs only in Practices II and III, only if the dairy cattle option has been chosen and only if the cattle have ingested an infectious dose of Salmonella. It is assumed that 48 hours will elapse before septicemia develops from the infection and that septicemia will last an additional 120 hr. The transfer is made twice daily, starting 48 hr after the animals are first fed the crop, at (THARV+STORAG+48) hr for Practice III and, in Practice II, 102 hr for Class A treated sludge, 793 hr (1 month+48 hr after TR14) for Class B treated sludge or 1523 hr (2 months+48 hr after TR14) for Class C treated sludge.

TR194 In Practice II, it is assumed that pathogens from the intestinal tract of infected animals may be deposited on the ground. Transfer of pathogens from Compartment 19, MANURE, to Compartment 4, SOIL SURFACE, is calculated once each day starting 13 hours after grazing begins (67 hours for Class A treated sludge, 1 month+13 hr after TR14 = 758 hours for Class B treated sludge and 2 months+13 hr after TR14 = 1488 hours for Class C treated sludge).

TR1914 A portion of the manure in Practice II will adhere to the surface of the cover crop. The times of transfer are the same as for TR194: transfer of pathogens from Compartment 19, MANURE, to Compartment 14, CROP SURFACE, is calculated once for each day starting 13 hours after grazing begins (67 hours for Class A treated sludge, 1 month+13 hr after TR14 = 758 hours for Class B treated sludge and 2 months+13 hr after TR14 = 1488 hours for Class C treated sludge.

TR1921 A portion of the manure in Practices II and III will adhere to the hide of the animals. This is of no concern for exposure when the dairy cattle option is used, but it is considered in the exposure calculations if the beef cattle option is used. In Practice II the times of this transfer are calculated as beginning 1 hour later than for TR194: transfer of pathogens from Compartment 19, MANURE, to Compartment 21, HIDE, is calculated once each day starting 14 hours after grazing begins. In Practice III the transfer is calculated once each day starting at (THARV+STORAG+14) hr, [THARV = P(69) and STORAG = P(80)]. In Practice II transfer occurs at 68 hours for Class A treated sludge, 1 month+14 hr after TR14 = 759 hours for Class B treated sludge and 2 months+14 hr after TR14 = 1489 hours for Class C treated sludge).

TR1922 A portion of the manure in Practices II and III will adhere to the udders of the cows. This is considered in the exposure calculations if the dairy cattle option is used. In Practice II the times of this transfer are calculated as beginning 1 hour later than for TR194: transfer of pathogens from Compartment 19, MANURE, to Compartment 21, HIDE, is calculated once each day starting 14 hours after grazing begins. In Practice III the transfer is calculated once for each day starting at a time (THARV+STORAG+14) hr, [THARV = P(69) and STORAG = P(80)]. This time must be at least 68 hours for Class A treated sludge, 1 month+14 hr after TR14 = 759 hours for Class B treated sludge and 2 months+14 hr after TR14 = 1489 hours for Class C treated sludge).

TR2118 Transfer of pathogens from Compartment 21, HIDE, to Compartment 18, MEAT, occurs in Practices II and III at TSLOTR [P(85)] hr. This transfer is made only if the beef cattle option is chosen.

TR2220 Transfer of pathogens from Compartment 22, UDDER, to Compartment 20, MILK, occurs in Practices II and III when the dairy cattle option is chosen. In Practice II the transfer occurs twice daily beginning 8 hours after grazing begins. In Practice III the transfer occurs twice daily beginning 8 hr after feeding of forage grown on sludge-amended soil begins, at (THARV+STORAG+8) hr, where THARV = P(69) and STORAG = P(80). In Practice II this transfer occurs at 62 hours for Class A treated sludge, 1 month+8 hr after TR14 = 753 hours for Class B treated sludge and 2 months+8 hr after TR14 = 1483 hours for Class C treated sludge.

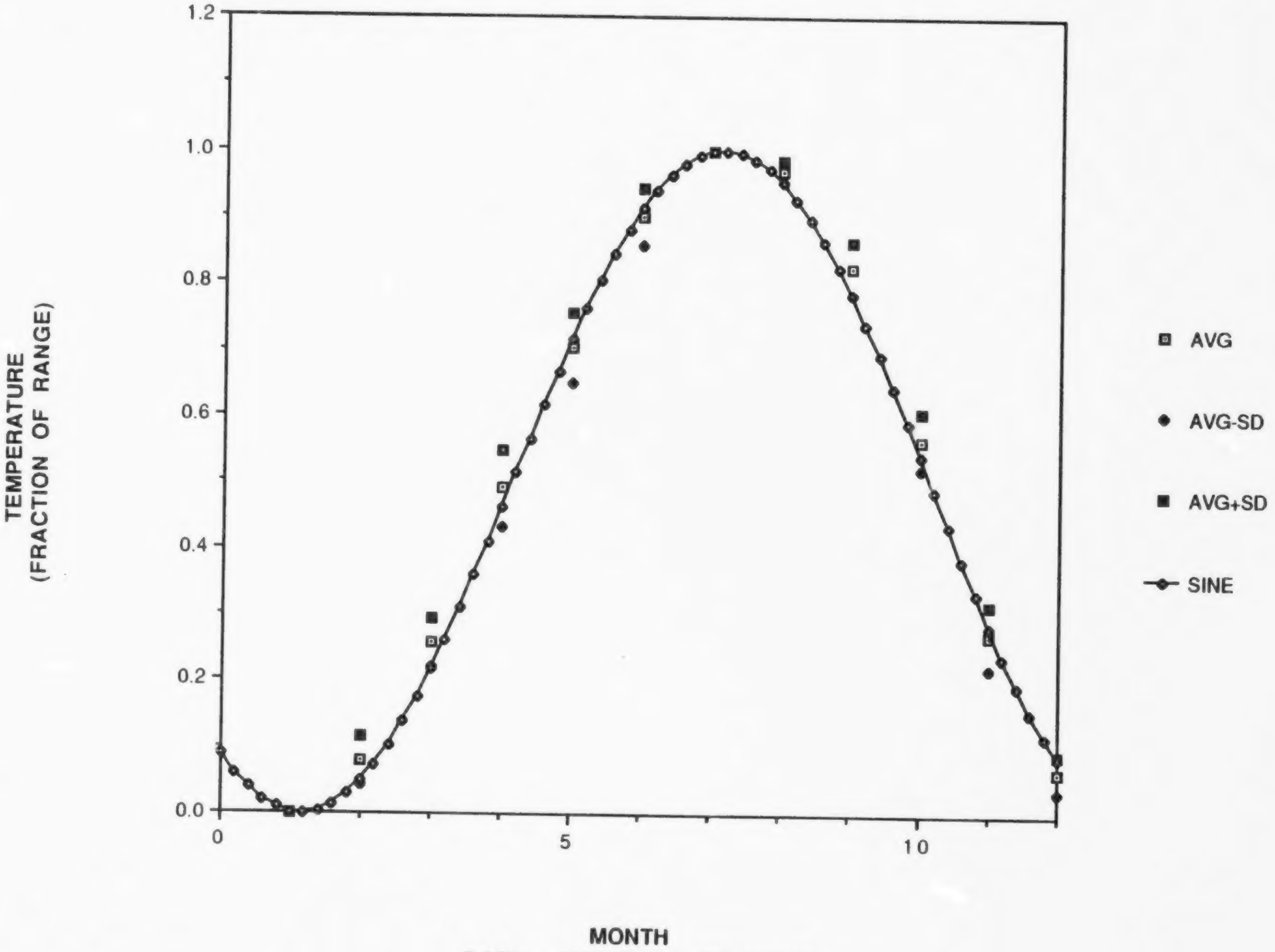
4.4. PROCESS FUNCTIONS

Process functions govern the increase or decrease in numbers of organisms within a compartment during each hour of the model run. For most compartments a temperature-dependent process function is calculated using the variables TEMP [P(8)], SLOPn [P(37) and P(39)] and NTRCPn [P(38) and P(40)]. TEMP is the ambient temperature for air and subsurface soil, and 5° C above ambient temperature for surface soil and crop surfaces. The value of TEMP is calculated by a function derived from the reported maximum (July) and minimum (January) average temperatures for the location being modeled. Annual temperature fluctuations can be fitted empirically to a sine curve with sufficient reliability for the purposes of this model. Table A-9 lists the normalized 40-year average monthly temperatures from several reporting stations throughout the United States (NOAA, 1981). In Figure 4-1, the means and standard deviations of these normalized values are graphed along with a curve defined by Equation 4-1:

$$F(M) = (0.5*\mathrm{Sin}(\pi*(M-4.15)/6)+0.5) \qquad (4\text{-}1)$$

The value M/12, indexed to the time of the year when the minimum and maximum temperatures occur by subtracting 4.15/12, gives the fraction of the yearly cycle represented by month M. This fraction multiplied by 2π is the variable whose sine defines the curve. Because the range of the sine curve is -1 to +1, the values are divided by 2 and increased by 0.5 to make the range 0 to +1. In the model, the starting time (day of the year, calculated from starting month and day) is used to index the temperature curve to the appropriate point in the cycle (ANDAY [P(34)]). This

TEMPERATURE VARIATION
FIT TO SINE FUNCTION



DATA: AVG OF 11 STATIONS
FIGURE 4-1

point is then incremented daily during the model run as variable ANDAX, which is used along with TMAX P(35) and TMIN P(36) to calculate temperature by Equation 4-2:

$$\text{TEMP} = [(\text{TMAX}+\text{TMIN})/2]+[(\text{TMAX}-\text{TMIN})/2*\text{SIN}(2*3.1416*\text{ANDAX}/365)] \quad (4\text{-}2)$$

TEMP is used to calculate temperature-dependent inactivation functions. Equation 4-2 is applied at the beginning of each call to the EVAL subroutine, which stores TEMP as variable P(8) for use in each compartment state subroutine, usually by Equation 4-3. Temperature-dependent inactivation rates (RHO) are calculated hourly for each compartment. SLOPES [P(37)] or SLOPEP [P(39)] and NTRCPS [P(38)] or NTRCPP [P(40)] are slope and intercept parameters A and B (for soil (S) or particulates (P)) in Equation 4-3:

$$\text{RHO} = N_0 \left(10^{-(10^{((A*\text{TEMP})-B)})}\right) \quad (4\text{-}3)$$

This equation was derived empirically by fitting a straight line to a logarithmic transform of data taken from the literature on inactivation rates of bacteria or viruses in moist or dry soil (Crane and Moore, 1986; Kibbey et al., 1978). In the case of viruses in soil, a change from TEMP to TEMP^2 in Equation 4-3 was required to fit the data adequately to a straight line. Representative values of slope and intercept for some pathogens and other bacterial species are given in Table A-10. Figure 4-2 shows the relation of die-off rates of Salmonella in soil to temperature, as given by Equation 4-3.

As an alternative to the temperature-dependent rate calculation, the user can enter the values of variables for growth or inactivation rates for four conditions. PROC variables are entered as exponential (base 10) rate constants and are converted by the program to hourly constants. HCRIT is used directly in the liquid droplet aerosol equations. The variable names and the associated conditions are listed in Table A-11. PROC1 is the hourly exponential rate constant for growth or inactivation of microbes in moist soil. This is the condition for Compartments 1 (APPLICATION), 2 (INCORPORATION), 4 (SOIL SURFACE), 8 (SUBSURFACE SOIL) and 14 (CROP SURFACE). PROC2 is the hourly exponential rate constant for inactivation of microbes on air-dried particulates. This is the condition represented by PARTICULATES (Compartment 5). PROC3 is the hourly exponential rate constant for inactivation or growth of microbes suspended in water. This is the condition for Compartments 6 (SURFACE RUNOFF), 9 (GROUNDWATER), 10 (IRRIGATION WELL), 11 (SURFACE WATER) and 12 (OFFSITE WELL). HCRIT is the exponential (per minute)

PROCESS FUNCTION (RHO) FOR
DIE-OFF OF SALMONELLA
IN MOIST SOIL

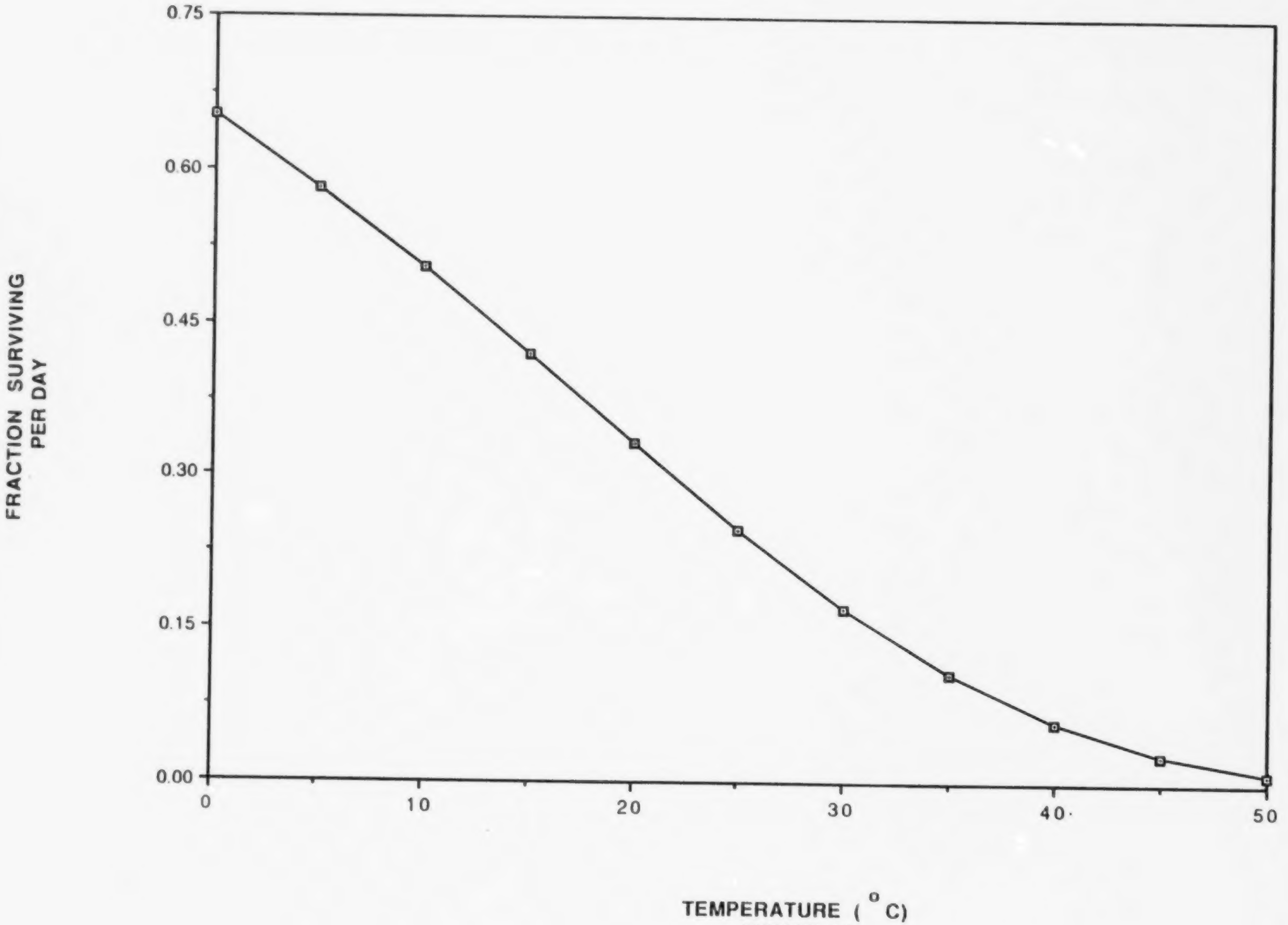


FIGURE 4-2

inactivation rate of microbes in liquid droplet aerosols (compartment 13, IRRIGATION AEROSOLS).

It is assumed that if the number of bacterial pathogens ingested exceeds the infective dose for cattle (10^9 Salmonella per animal) the number of pathogens in Compartment 19, MANURE, will increase. Information on the rate of increase and the final level of pathogen populations in gastroenteritis of cattle is limited, so the values used in the program are somewhat arbitrary. The population of MANURE in infected cattle is arbitrarily set at $4*10^{12}$ per animal. Because transfers TR417 and TR1417 are included in this population, the process function is given as:

$RHO17 = COWS*4*10^{12}-(TR417+TR1417)$, if $(TR417+TR1417) \geq COWS*10^9$, where COWS = P(79). In this case, the process function is actually used as a transfer factor. Process functions for Compartment 19, MANURE, are the same as for pathogens in soil.

In two compartments, 18 (MEAT) and 20 (MILK), it is assumed that bacterial pathogens will grow at a rate of $RHOn = 0.076*N(n)$ per hr (doubling time of 9.5 hr). No growth is assumed in these compartments for parasites or viruses. In Compartments 21 (HIDE) and 22 (UDDER) there is a daily transfer of pathogens from Compartment 19 (MANURE). These populations are assumed to be lost at a constant rate over the next 24 hr ($RHOn = (-1/24)*N(n)$ per hr).

Process functions used in the model are summarized in Table A-12.

5. COMPLEX TRANSFER FUNCTIONS

5.1. PARTICULATE EMISSIONS FOLLOWING APPLICATION/INCORPORATION

Application and incorporation of sewage sludge may result in the generation of particulate clouds or liquid aerosols, either onsite or offsite. In addition, wind erosion is assumed to generate particulate clouds. The generation of particulate emissions by tilling is described in Section 5.1.1., wind erosion is described in Section 5.1.2., calculations for onsite exposures are described in Section 5.1.3. and calculations for offsite exposure are described in Section 5.1.4. Liquid droplet aerosols are described in Section 5.2., surface runoff and sediment transport in Section 5.3., and subsurface transport in Section 5.4.

5.1.1. Tilling Emissions. It is assumed in Practices I, IV and V that liquid or composted sludge applied to the soil is incorporated by tilling. If the soil has a bulk density of 1.33 g/cm^3, the dry mass of the surface soil layer is $2 \cdot 10^6$ kg/ha (Naylor and Loehr, 1982; Donahue et al., 1983). As a result of the mixing of sludge with soil during incorporation, the initial concentration of pathogens in the surface soil is given by the following equation:

$$CP = CS \cdot AR/MS$$

where:

CP = concentration of pathogens in soil (number/g)

CS = concentration of pathogens in sludge (number/kg)

AR = application rate (kg/ha)

MS = mass of soil = $(2 \cdot 10^6$ kg/ha$) \cdot (10^3$ g/kg$) = 2 \cdot 10^9$ g/ha.

Particulate emissions result from spreading and tilling liquid sludge in Practice I and are assumed to be similar to emissions for other agricultural tilling (using a disc, land plane or sweep plow), as described by U.S. EPA (1983a). This calculation is called beginning at 24 hours to compute the transfer from Compartment 2, INCORPORATION, to Compartment 3, APPLICATION/INCORPORATION EMISSIONS. Additional tilling, at a time and for a duration specified by the user, is modeled by the same calculation as for the transfer from INCORPORATION to APPLICATION/INCORPORATION EMISSIONS, except in this case the calculation is performed for the transfer from Compartment 4, SOIL SURFACE, to Compartment 3, APPLICATION/INCORPORATION

EMISSIONS. In Practice I the calculation is done once for each hour up to AREA/5, where AREA [P(7)] is the area of the field in hectares, assuming that one tractor operator will till 40 ha in an 8-hour day. In Practices IV and V, the length of time is AREA/0.005.

The quantity of dust generated by tilling is empirically described as:

$$E = 6.04*k*s^{0.6}$$

where:

E = emission factor (kg/ha)

k = particle size multiplier (dimensionless), EPSMLT, P(26)

s = fractional silt content of soil, ESILT, P(27).

The particle size multiplier (k) varies with particle size range as follows:

Size range	<30 μm	<15 μm	<10 μm	<5 μm	<2.5 μm
k value	0.33	0.25	0.21	0.15	0.10

The default value for the silt content of the soil [ESILT, P(27)] is 40%, and that for the size of particulates inhaled and ingested [EPSMLT, P(26)] is the <30 μm range. The value of 40% silt corresponds to a loam or clay loam soil, and the size class chosen yields the highest estimated k factor, making this a conservative assumption.

It is assumed that the sludge is diluted by the surface soil (a factor of $2*10^6$). Thus the transfer equation, which includes a factor for pathogen load, is

$$TR23 = ASCIN*6.04*EPSMLT*(ESILT^{0.6})/2.0*10^6 \text{ or}$$

$$TR43 = N(4)*6.04*EPSMLT*(ESILT^{0.6})/2.0*10^6,$$

where:

ASCIN = P(3)
EPSMLT = P(26)
ESILT = P(27).

These equations occur in subroutines STA2 and STA4 of subroutine EVAL1 and subroutine STD4 of subroutine EVAL4.

5.1.2. Wind Erosion. Compartment 5, PARTICULATES, represents a cloud of airborne particles generated from Compartment 4, SOIL SURFACE, at a concentration determined by models described below for wind erosion. The time of initiation, strength and duration of the wind generating the particulate cloud can be specified by the user;

default values are:

Wind speed [WINDSP, P(25)] = 18 m/sec (40 mph)
Duration [DWIND, P(24)] = 6 hours
Beginning time [TWIND, P(23)] = 60 hours
Critical wind speed [SCRIT, P(29)] = 7.5 m/sec.

The concentration of wind-generated dust in the air will depend on the soil composition, moisture, and wind speed. It is assumed that dry conditions exist, especially since particles of a size subject to wind erosion dry quickly. There is a threshold wind speed [critical wind speed, SCRIT, P(29)] below which wind erosion does not occur. That speed varies with soil type, terrain and amount of cover vegetation, and, because of large variations in wind speed close to the ground, is typically corrected to a height of 7 m. In this example, the default value of the corrected threshold wind speed is 7.5 m/s. The following estimates are based on the document Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites (U.S. EPA, 1985), which summarizes methodologies to estimate concentrations of airborne pollutants. Assuming unlimited erosion potential (no ground cover), the emission factor for particles $<10\ \mu m$ in diameter (E_{10}) is given by the following equation (Gillette, 1981):

$$E_{10} = 0.036 \cdot (1-V) \cdot ([u]/u_t)^3 \cdot F(x)$$

where:

E_{10} = PM_{10} emission factor (annual average emission rate per unit area, in $g/m^2/hr$)

V = fraction of contaminated surface with cover vegetation (0 for bare soil). V is represented by the variable COVER [P(30)].

[u] = mean wind speed in m/sec [WINDSP, P(25)]

u_t = threshold value of wind speed in m/s, corrected for height of 7 m (SCRIT, [P(29)].

x = $0.886 \cdot (u_t/[u])$

F(x) = an empirical function tending to 1.91 as x becomes less than 0.5, and toward 0 as x becomes greater than 3. In practice, the calculation will be of little interest if [u] is not greater than u_t, so x will always be less than 0.886, and F(x) will be sufficiently close to 1.91 that use of that value will cause only a slight overestimate of E_{10}.

An additional correction is made for the amount of soil in the compartment: $(2 \cdot 10^6$ kg/ha of soil$) \cdot (10^3$ g/kg$)/(10^4$ m^2/ha$) = 2 \cdot 10^5$ g/m^2. Taking these factors into account, the transfer equation is

$$TR45 = 0.069*(1-COVER)*((WINDSP/SCRIT)^{3})*N(4)/(2*10^{5})$$

and is found in the ST*4 subroutines of subroutine EVAL1-EVAL5. While it is more likely that viruses or bacteria will be found in wind-borne particulates than the heavier ova of parasites, each model pathogen is treated in the same manner. A graph showing the relationship of TR45/N(4) to wind speed is given in Figure 5-1. It can be seen from this graph that the yield of particulates increases with wind speed but is more sensitive to the threshold value SCRIT.

5.1.3. Onsite Exposures. For onsite exposure, the concentration may be estimated by the following equation (Gifford and Hanna, 1973)

$$P = Cq_a/[u]$$

or by the similar equation (Pasquill, 1974)

$$P = q_a x/[u]h'$$

where:

C = constant dependent on characteristics of the pollutant and source. Assume $C = x/\sigma_z$ and $\sigma_x = 0.012x$ (Gifford & Hanna, 1973); then C = 83.3

q_a = area emission rate

[u] = mean wind speed over emission area, WINDSP, P(25)

x = distance from upwind edge of source to receptor, 400 m

h' = height of the box containing the cloud, 5 m.

These equations show satisfactory agreement at the distance chosen, which represents the human receptor at the downwind edge of a 10-ha field (250m * 400m). The former calculation, which implies an equilibrium condition at long distances but which may give an overestimate for short distances, is used in the model:

$$XPRTC5 = (0.00833*N(5))/(WINDSP*3600)$$

where:

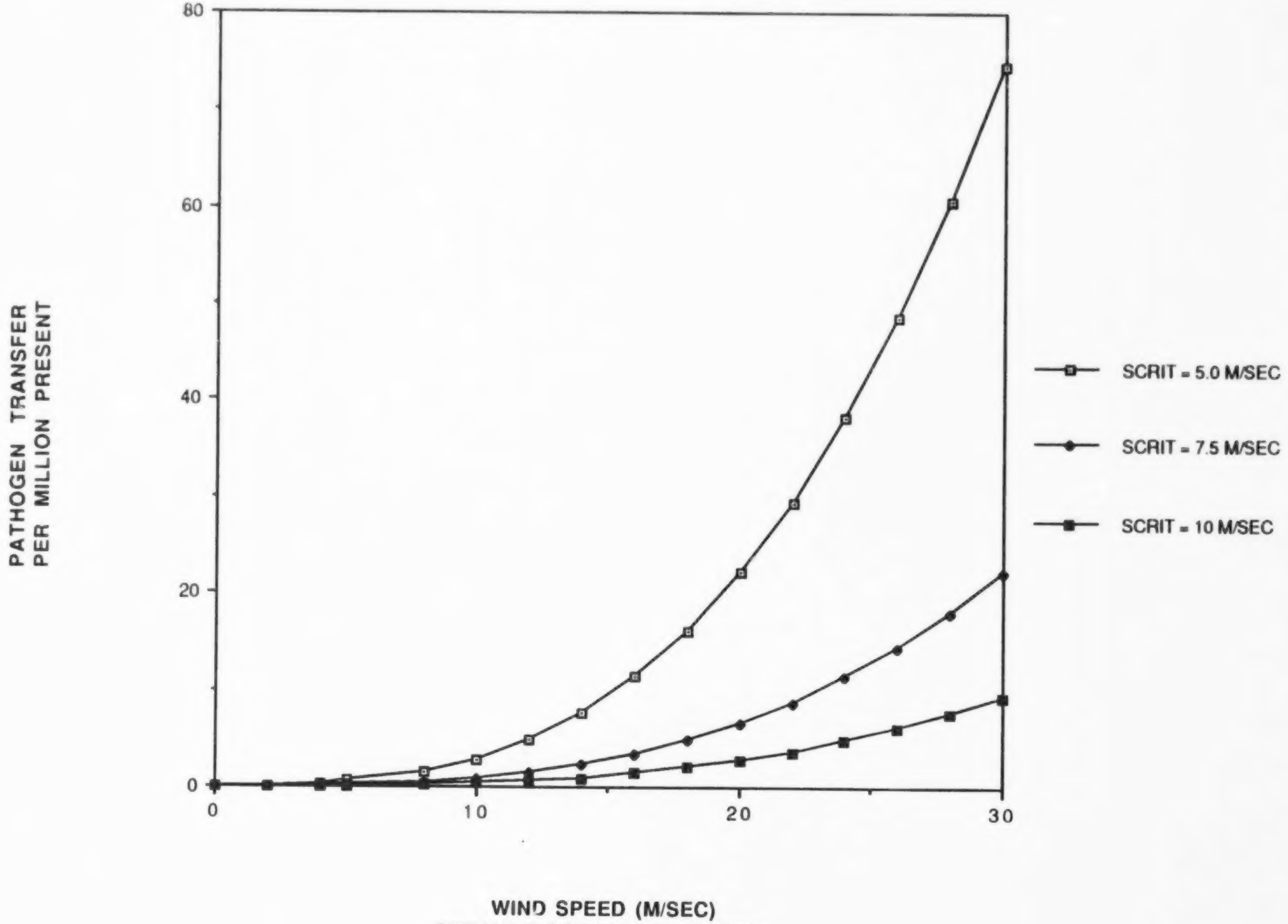
0.00833 = C (above)$*10^{-4}$ ha/m^2

WINDSP = wind speed in m/sec [P(25)]

3600 = sec/hr.

This calculation is done in Subroutine PARTIC of Subroutine RISK.

WIND EROSION FUNCTION



DEFAULT SCRIT = 7.5 M/SEC
FIGURE 5-1

5.1.4. Offsite Exposures. For offsite emissions, a Gaussian-plume model is used. Particulates are assumed to be evenly distributed throughout the defined volume of an aerosol cloud and the pathogens associated with airborne material are assumed to be uniformly distributed among the particles.

The particulate-exposure risk calculation assumes that particulate-associated pathogens are disseminated downwind after generation and that generation is an instantaneous event occurring at ground level, with no subsequent plume rise. The downwind movement leads to a reduction in the concentration of airborne pathogens as a result of dispersion and inactivation. The reduction in pathogen concentration due to dispersion is estimated using a modification of Pasquill's diffusion equation, which describes release from a ground-level source with no plume rise (U.S. EPA, 1985).

$$C_{x,y,z} = \frac{Q_T}{\pi \sigma_y \sigma_z u} \exp(-y^2/2\sigma_y^2) \ast \exp(-z^2/2\sigma_z^2) \qquad (4\text{-}4)$$

where:

$C_{x,y,z}$ = number of pathogens per cubic meter of air at a downwind location described by the coordinates x,y,z after release from a source at ground level

Q_T = rate of release of pathogens from the source

$\sigma_{y,z}$ = standard deviation of the pathogen concentration in a perpendicular (y) and vertical (z) direction

u = mean wind speed (m/s).

In the risk calculations, as a worst case, the exposed individual is assumed to be standing directly downwind (default y=0). The default value for height of exposure is 1.6 m. The user may specify the distance x in meters between the source and the exposed individual; however limitations in the model require that the distance be at least 100 m for accurate results. The dispersion parameters ($\sigma_{y,z}$) set in the model were determined for neutral atmospheric conditions.

The reduction in pathogens due to inactivation is affected by a number of factors including the age of the cloud, temperature, relative humidity, and solar radiation (Camann et al., 1978; Dimmick and Akers, 1969; Gregory, 1973; Lighthart and Frisch, 1976). The following equation was used to estimate inactivation of pathogens dispersed as shown in Equation 4-4.

where: I = exp(dx/u)

I = inactivation of the pathogen population

d = aerosol inactivation rate constant for a particular pathogen

x = user-specified distance in meters from the source. The default value for this variable (XDIST) is 200 m.

u = user-specified wind speed (m/s). The default value for this variable is WINDSP [P(25)] = 18 m/s for windstorm and BREEZE [P(32)] = 4 m/s for irrigation.

The inactivation rate constants used in the model for water suspensions are 50th percentile values for the aerosol inactivation rates of Salmonella and enteroviruses (Camann et al., 1978) and an estimated value for Ascaris. For particulate clouds it is assumed that association of microbes with the particles will be protective, and a decay rate equal to that in air-dried soil is used.

The combined effects of dispersion and inactivation are in Equation 4-5, which predicts the final pathogen concentration.

$$C_{x,y,z} = \frac{Q_T}{\pi \sigma_y \sigma_z u} \exp(-y^2/2\sigma_y^2) * \exp(-z^2/2\sigma_z^2) * \exp(dx/u) \qquad (4\text{-}5)$$

where:

$C_{x,y,z}$ = number of pathogens per cubic meter of air at a downwind location described by the coordinates x,y,z after release from a source at ground level

Q_T = calculated rate of release of pathogens from the source compartment at a given time ((mass/sec)*(pathogens/mass))

x = user-specified distance in meters from the source. The default value for this variable (XDIST, variable 35 in Subroutine RISK) is 200 m. Because the Gaussian-plume model is not accurate at short distances, a warning is included in the menu that XDIST should be at least 100 m.

y = lateral distance of the receptor in meters from a line directly downwind of the source. The default value for this variable (YDIST, variable 36 in Subroutine RISK) is 0 m.

z = receptor height in meters. The default value for this variable [HT, P(33)] is 1.6 m.

σ_y = 0.0295x, the standard deviation of particulate concentration perpendicular to the wind direction for a specified distance x in meters (Turner, 1969)

σ_z = 0.012x, the standard deviation of particulate concentration vertically (Turner, 1969)

d = inactivation rate constant (HCRIT). Values for soil particles are the same as for bulk soil. Values for water suspensions (Camann et al., 1978):

Salmonella -0.028/second
Ascaris -0.01/second
enterovirus -0.002/second

u = user-specified wind speed (m/s). The default value for this variable is WINDSP [P(25)] = 18 m/s for windstorm and BREEZE [P(32)] = 4 m/s for irrigation.

These factors are combined in Subroutine PARTIC of Subroutine RISK in the equation

$$\mathrm{CHI} = \mathrm{N(5)} \bullet (\mathrm{AREA}/3600)/(3.14 \bullet \mathrm{SIGMAY} \bullet \mathrm{SIGMAZ} \bullet \mathrm{WINDSP}) \bullet \mathrm{EXP}[(\mathrm{HCRIT} \bullet \mathrm{XDIST}/\mathrm{WINDSP}) - (\mathrm{YDIST}^2/2 \bullet \mathrm{SIGMAY}^2) - (\mathrm{HT}^2/2 \bullet \mathrm{SIGMAZ}^2)]$$

where:

AREA = area of application, P(7)
WINDSP = wind speed in m/sec, P(25)
HCRIT = variable set during input of die-off rates
XDIST = variable 34 of Subroutine RISK
YDIST = variable 35 of Subroutine RISK
SIGMAX = 0.0295•XDIST (Turner, 1969)
SIGMAY = 0.0295•XDIST (Turner, 1969)
SIGMAZ = 0.012•XDIST (Turner, 1969).

This calculation is done once for each hour, and the result is summed with the aerosol emission CHIA (see Section 5.2 below) in Subroutine OFFSITE of Subroutine RISK. The variation of CHI with XDIST using default values for the other variables is illustrated in Figure 5-2. Note that at distances less than 100 m (vertical bar) the equation yields an increasing concentration with distance, as a result of limitations in the mathematical model. Beyond 100 m, the concentration drops with distance; it is higher for lower

AIR DIFFUSION MODEL
OFFSITE TRANSPORT

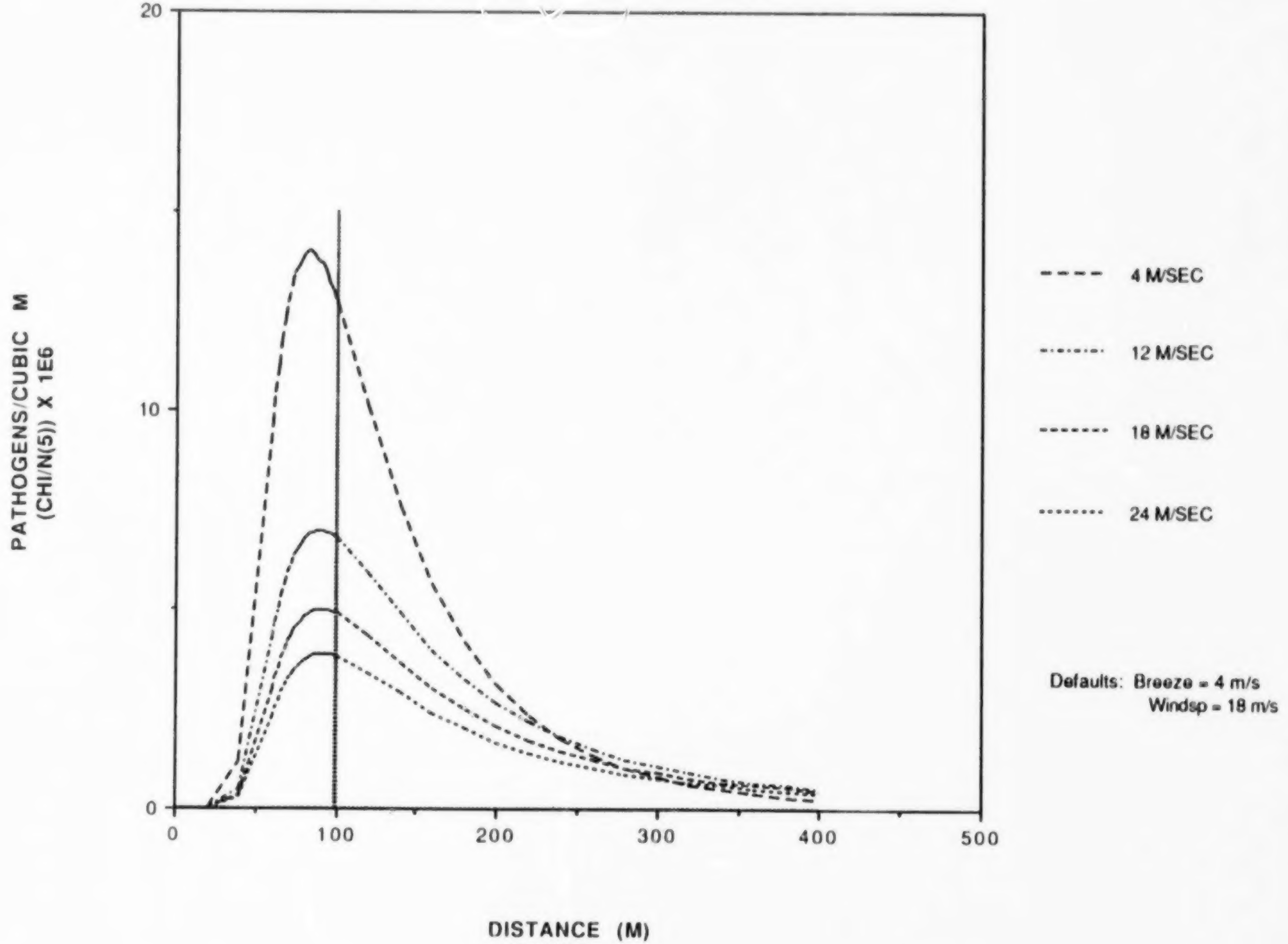


FIGURE 5-2

wind speed, when there is less dispersion of the cloud.

For aerosol and sludge intake it is assumed that the average inhalation rate is 20 m^3/day or 5/6 m^3/hour. The pathogen exposures from offsite particulates are assumed not to exceed 16 hours per day, but for ease of computation, the inhalation rate is converted to $(5/6 * 16/24) = 0.56$ m^3 per hour, and exposures in the compartment are accumulated hourly into a 24-hour pathogen exposure.

5.2. LIQUID DROPLET AEROSOLS

Application of liquid sludge by spread-flow or injection practices assumes no liquid droplet aerosol offsite emissions. Spray application of liquid sludge is assumed to generate aerosols that are transported offsite by a wind whose speed can be chosen by the user (default value is 4 m/s). Details of the method of calculation and sample results are given above (Section 5.1.4.) in the discussion of particulates. A value for offsite emissions by droplet aerosols (CHIA) is calculated by an equation analogous to that for CHI:

$$\begin{aligned}\mathrm{CHIA} = {} & [\mathrm{ACONC}/(3.14*\mathrm{SIGMAY}*\mathrm{SIGMAZ}*\mathrm{BREEZE})] \\ & *\mathrm{EXP}[(\mathrm{HCRIT}*\mathrm{XDIST}/\mathrm{BREEZE})-(\mathrm{YDIST}^2/2*\mathrm{SIGMAY}^2) \\ & -(\mathrm{HT}^2/2*\mathrm{SIGMAZ}^2)]\end{aligned}$$

where:

$$\mathrm{ACONC} = \mathrm{AREA}*\mathrm{AEREFF}*\mathrm{SOURCE}/3600$$

$$\begin{aligned}\mathrm{SOURCE} = {} & [(1-\mathrm{DILIRR})*\mathrm{N}(10)*\mathrm{IRRATE}/(100*\mathrm{AQUIFR}*\mathrm{POROS})]+ \\ & (\mathrm{DILIRR}*\mathrm{COUNT}*\mathrm{IRRATE}*(5*10^3))\end{aligned}$$

AREA = area of application, P(7)

AEREFF = efficiency of aerosol formation, P(31)

DILIRR = fractional dilution of irrigation water, P(18)

IRRATE = irrigation rate (cm/hr), P(20)

AQUIFR = thickness of aquifer (m), P(9)

POROS = porosity of aquifer, P(10)

COUNT = pathogen concentration in diluting irrigation water, P(22)

BREEZE = speed of prevailing wind (m/sec), P(32)

HT = height of downwind receptor (m), P(33)

HCRIT = variable set during input of die-off rates

XDIST = variable 34 of the Subroutine RISK variables

YDIST = variable 35 of the Subroutine RISK variables

SIGMAX = 0.0295*XDIST (Turner, 1969)

SIGMAY = 0.0295*XDIST (Turner, 1969)

SIGMAZ = 0.012*XDIST (Turner, 1969).

This calculation is done by Subroutine PARTIC of Subroutine RISK and the result is summed with CHI in Subroutine OFFSITE of Subroutine RISK.

For the spray option, a default application rate of 0.5 cm/hour is used, as in the case of irrigation. The efficiency of aerosol formation during spraying has been estimated as about 0.1% or less (Sorber et al., 1984). Inactivation rates are taken to be the 50th percentile values for the aerosol inactivation rates of Salmonella and enteroviruses (Camann et al., 1978) and an estimated value for Ascaris. They are as follows:

d = -0.028/second (Salmonella)
-0.01/second (Ascaris)
-0.002/second (enterovirus).

5.3. SURFACE RUNOFF AND SEDIMENT TRANSPORT

Surface runoff occurs when the amount of rainfall or spray irrigation received by the field exceeds the retention capacity of the soil. The amount of runoff is calculated by Subroutine RAINS, which is called once for each rainfall or irrigation event. This subroutine uses the Modified Universal Soil Loss Equation (Williams, 1975), which calculates the amount of soil erosion as a function of soil condition and use and of the peak discharge, calculated from a constructed excess rainfall hyetograph. Input to the subroutine includes the time, duration, and amount of rainfall. Rainfall is modeled as a single event whose intensity increases linearly with time to a peak at a user-specified storm-advancement coefficient (default value 0.4) and subsequently falls linearly to the end of the rain. The composite transport resulting from excess rainfall serves as the transfer function from Compartment 4, SOIL SURFACE to Compartment 6, SURFACE RUNOFF. Irrigation is assumed to be controlled so that it does not cause surface runoff. It is also assumed that dikes or diversion channels will prevent surface runoff from entering the treatment area. Therefore, surface runoff and sediment transport are considered for the treatment area only. Figure 5-3 shows the response of surface runoff to changes in the duration and total amount of rainfall.

Most soil microorganisms are associated with soil particles. A fraction of these, however, will be suspended by added soil surface water and will be transported in suspension by surface runoff. Studies have shown that the fraction of microorganisms suspended by excess water is dependent on properties of the soil as well as on type of microorganism (Burge and Enkiri, 1978; Drewey and Eliassen, 1968; Gerba el al., 1975; Marshall, 1971; Reddy et al., 1981). Data on retention of viruses and bacteria can be fitted empirically to an equation describing a linear chemical adsorption isotherm:

$$\mathrm{PARTIC} = \mathrm{K} * \mathrm{SUSP}$$

where:

PARTIC = concentration of soil-bound organisms, number/gram

K = retention coefficient

SUSP = concentration of suspended organisms, number/ml solution.

Reported values of K range from 260-1900 for bacteria (Matson et al., 1978) and from 4.6-161 for viral particles (Burge and Enkiri, 1978).

Because the total number of organisms in the compartment is the sum of bound and suspended organisms (TOTAL = PARTIC+SUSP), the number of suspended organisms is

$$\mathrm{SUSP} = \mathrm{TOTAL}/(1+\mathrm{K}) \text{ or}$$

$$\mathrm{SUSP}/\mathrm{TOTAL} = 1/(1+\mathrm{K})$$

The constant 1/(1+K) is the variable SUSPND [P(45)]. Default values for SUSPND vary with pathogen type and also with land use practice; it is assumed that suspension of organisms in soil surface water is less when there is a grass cover (Practices II, III, and V) than when there is a substantial fraction of bare ground (Practices I and IV). Default values of SUSPND are given in Table A-3.

5.4. GROUNDWATER AT AN OFFSITE WELL

Computer models for solute transport in groundwater have been applied to the transport of microbes in soil (Haridas, 1983; van Genuchten, 1978, 1986). Transport models must include terms for the death or inactivation of microbes, filtration,

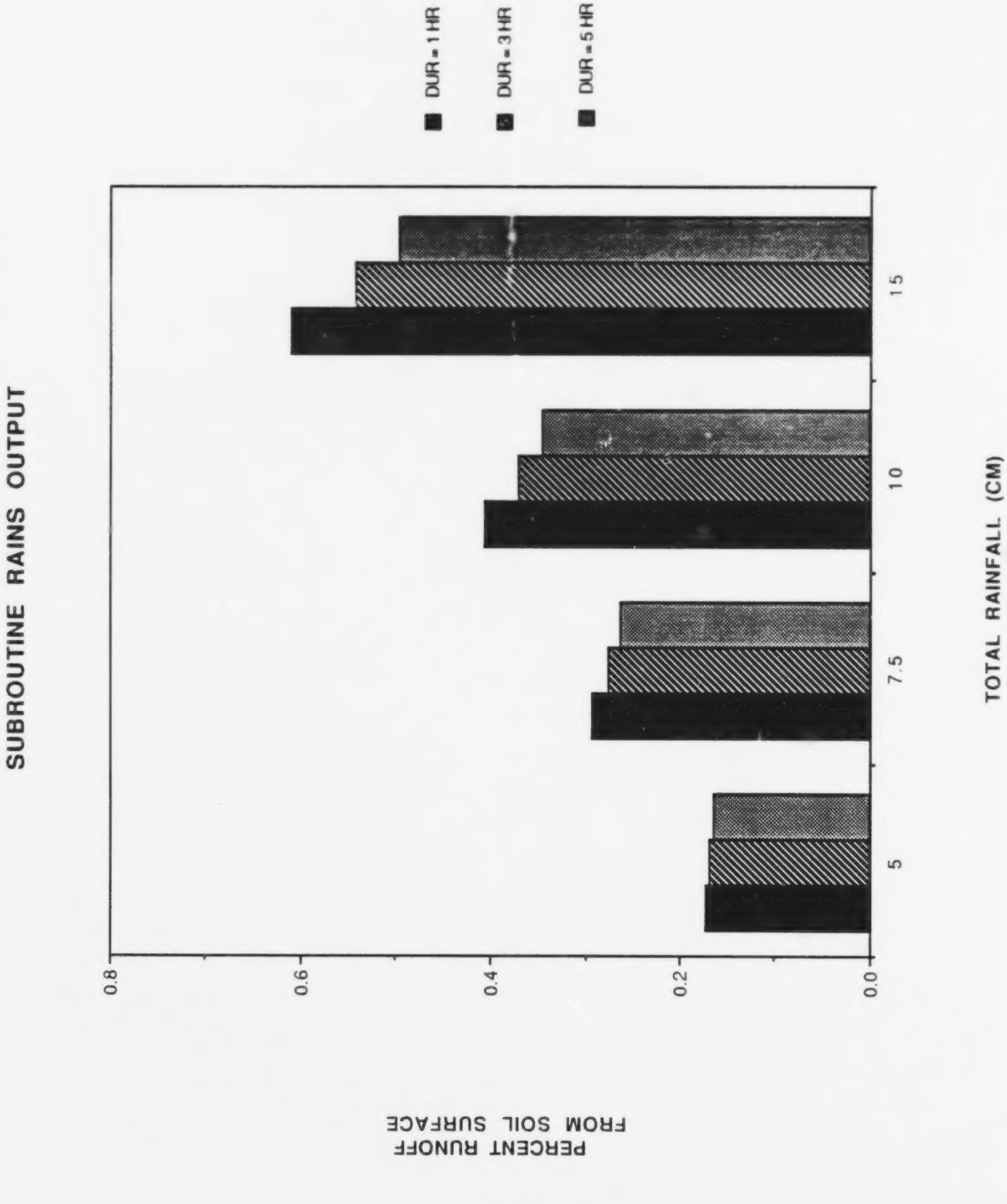

SUBROUTINE RAINS OUTPUT
PERCENT RUNOFF FROM SOIL SURFACE
0.0
0.2
0.4
0.6
0.8
5
7.5
10
15
TOTAL RAINFALL (CM)
DUR = 1 HR
DUR = 3 HR
DUR = 5 HR

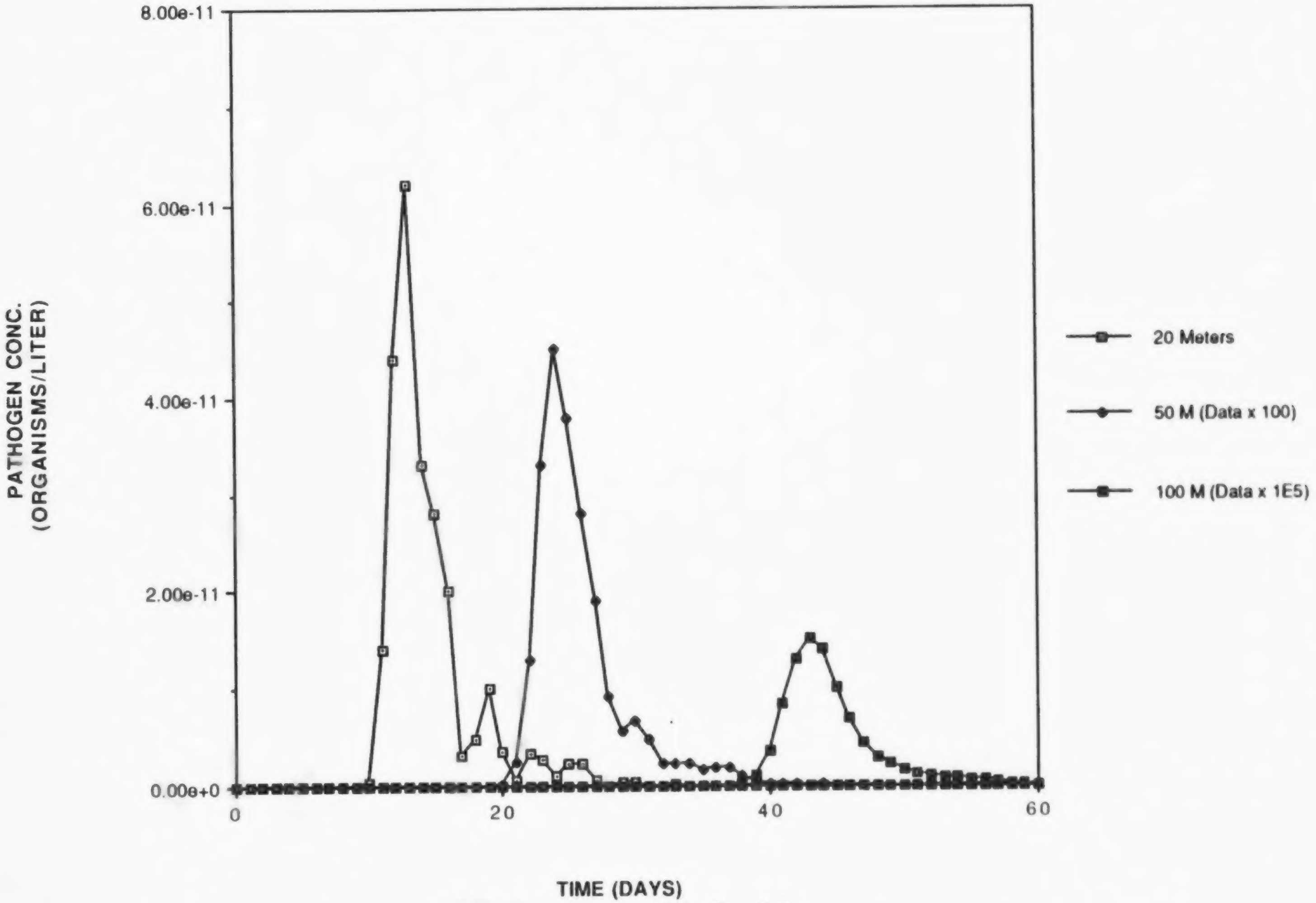
FIGURE 5-3

adsorption and advection during transport. Clogging of soil pores by filtration and the subsequent declogging by sloughing off of biofilm can be modeled (Haridas, 1983), but time-averaged values for retardation are probably sufficient and are more readily estimated. The mathematical description used in this report is a one-dimensional solution, contained in a program named EXACT.FORTRAN, of the advection-dispersion equation for solutes (van Genuchten and Alves, 1982). Input parameters for the model include retardation coefficients for saturated soil, as well as distance from source (upper boundary of groundwater or location in field) to output (drinking water well), velocity of water in the soil, hydrodynamic dispersion, and filter efficiency. It must be noted that the value of the retardation coefficient R is chosen to represent poor adsorption of microbes to soil particles during saturated flow in the aquifer. The response of the groundwater transport subroutine to variations in input parameters is illustrated in Figures 5-4 - 5-6. Figure 5-4 shows a dramatic decrease in pathogen concentration with distance, as well as a loss of resolution of the individual pulses of pathogens into the groundwater. Note that in Figure 5-4 the values for the 50-m distance are scaled by a factor of 100 and those for 100 m are scaled by 10^5 to show their position; otherwise they would not be discernible on the graph. Figure 5-5 shows a decrease in pathogen concentration at the well as a function of decreasing bulk flow velocity, again related primarily to time and die-off of microorganisms. Figure 5-6 shows the profound effect of the hydrodynamic dispersion coefficient on the pathogen concentrations at the well and on the time required for the peak concentration to arrive at the well.

Accurate values for retardation coefficient R are not known; values may be very high for extreme adsorption, filtering or clogging or as low as 0.5 for selective flow of pathogens through large pores and channels (Keswick et al., 1982; Bradford, 1987; Matthess et al., 1988). For the saturated flow option, a default value of 1 is used.

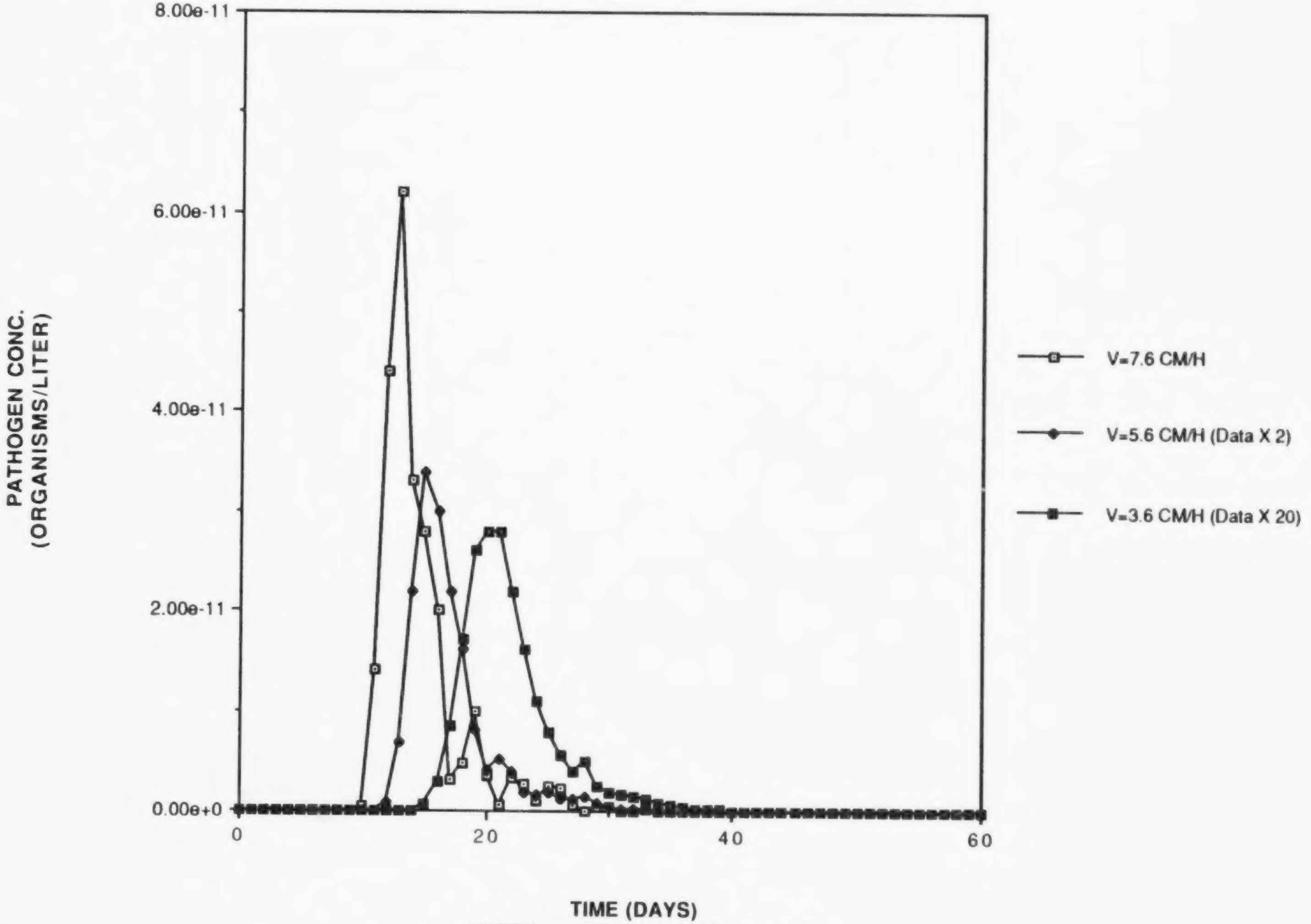
Both surface soil and subsurface soil immobilize microorganisms to some extent. As input into the transport subroutine, the surface soil is represented as retaining all but 0.05% of bacteria and 0.1% of virus particles. The default fraction for transport of bacterial and viral pathogens through the unsaturated zone is 0.1%. Transport through the saturated zone is modeled for a default distance of 50 m from the edge of the field, with the source of saturated flow taken as a point source containing all of the contribution from 1 ha.

EFFECT OF DISTANCE ON CONTENTS OF WATER WELL

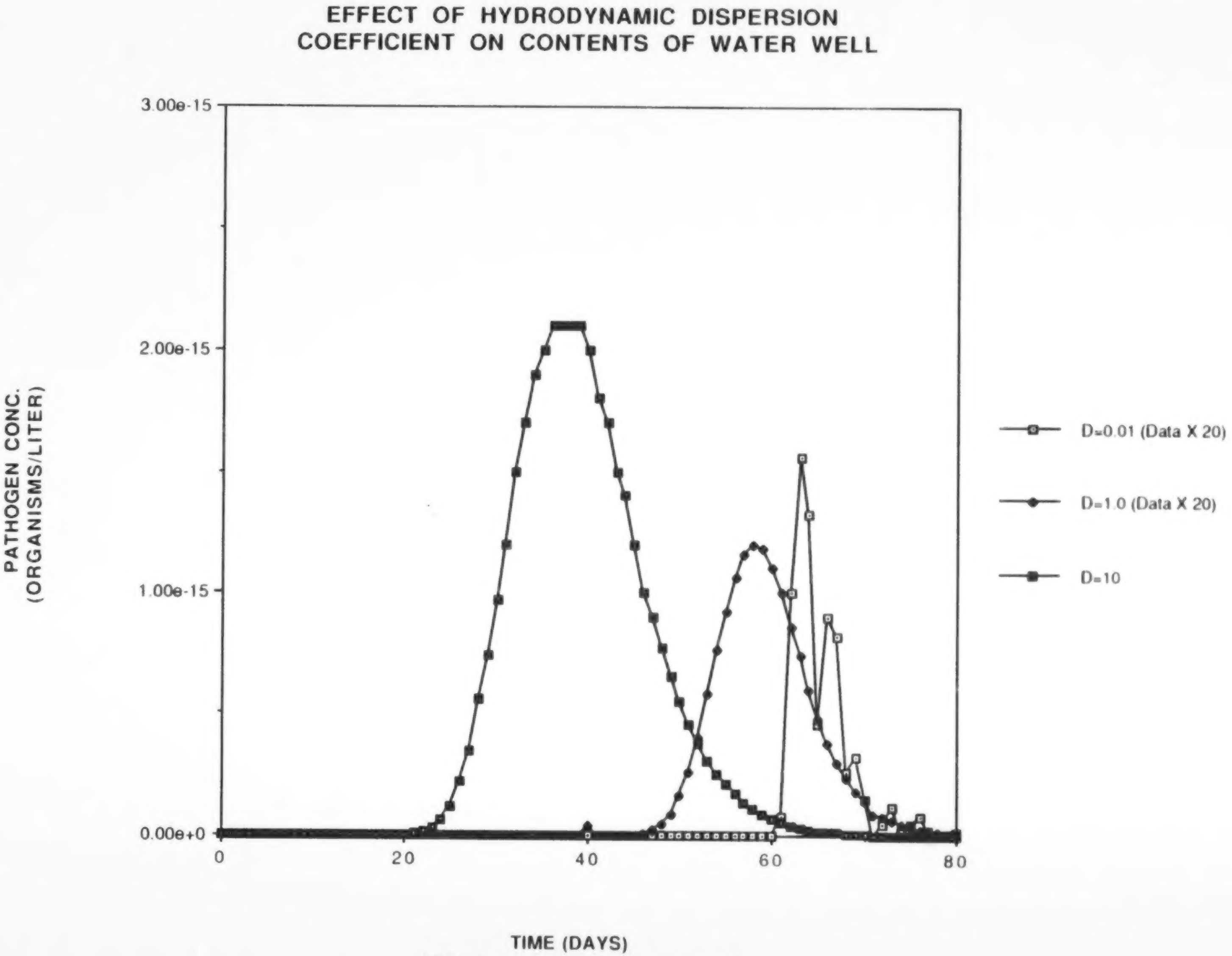


ASCRS = 1E5; V = 7.6; R = 0.7
FIGURE 5-4

EFFECT OF GROUNDWATER VELOCITY ON CONTENTS OF WATER WELL



ASCRS = 1E5; X = 20M; R = 0.7
FIGURE 5-5


EFFECT OF HYDRODYNAMIC DISPERSION COEFFICIENT ON CONTENTS OF WATER WELL

ASCRS = 1E5; X = 50M; V = 3.6
FIGURE 5-6

6. SAMPLE INPUT AND OUTPUT

In this section a sample model run is presented, showing the program's prompts, typical input responses to the prompts and the resulting output data tables. The sample run is for Practice I, using Salmonella in liquid sludge as the pathogen of interest. An unrealistically high value for pathogen concentration in the sludge and artificial values for THARV and for subsurface transport are used in order to generate data for comparison with the user's model run.

6.1. INPUT

In this presentation, the program's prompts are printed in normal type face, and the user's inputs are in bold type.

```
        MICROBIAL RISK ASSESSMENT FOR
LAND APPLICATION OF MUNICIPAL SEWAGE SLUDGE


              VERSION 3.1
        U.S. EPA, OCTOBER 1989



      DO YOU WANT TO ENTER VALUES FROM
        THE KEYBOARD OR FROM A FILE?
            (ENTER "K" OR "F")
```

If your response is **F**, you will be prompted:

```
      ENTER THE NAME OF THE INPUT FILE.
```

If your response is **K**, you will be prompted:

```
      ENTER A NAME FOR THE OUTPUT FILE.
       YOU MAY USE UP TO 8 CHARACTERS.
```

TEST

```
 *** SLUDGE PATHOGEN MODEL ***


ENTER VALUES FOR THE FOLLOWING
          (PRESS RETURN AFTER EACH):

     1. END TIME OF PRACTICE IN DAYS    20
     2. PRINTING SAMPLE RATE IN HOURS    8


PROVIDE PRACTICE NUMBER
YOUR CHOICES ARE:
    1   APPLICATION OF LIQUID SLUDGE FOR PRODUCTION
        OF COMMERCIAL CROPS FOR HUMAN CONSUMPTION

    2   APPLICATION OF LIQUID SLUDGE TO
        GRAZED PASTURE

    3   APPLICATION OF LIQUID SLUDGE FOR PRODUCTION
        OF CROPS PROCESSED FOR ANIMAL CONSUMPTION

    4   APPLICATION OF DRIED OR COMPOSTED SLUDGE
        TO RESIDENTIAL GARDENS

    5   APPLICATION OF DRIED OR COMPOSTED SLUDGE
        TO RESIDENTIAL LAWNS
1


PROVIDE PATHOGEN TYPE

YOUR CHOICES ARE:
     1   SALMONELLA    (BACTERIA)
     2   ASCARIS        (PARASITE)
     3   ENTEROVIRUS   (VIRUS)
1

THE VARIABLES LISTED BELOW MAY BE OPTIONALLY
CHANGED FROM THEIR DEFAULT VALUES:

        POPL(1-22)  (INITIAL PATHOGEN POPULATIONS
                    OF COMPARTMENTS IN PRACTICE.
                    [SEE MANUAL FOR DESCRIPTIONS.]
                    DEFAULT = 0.0)

1. TYPE THE NUMBER "1" TO ACCEPT THE CURRENT
   VALUES AND CONTINUE WITH THE PROGRAM.

2. TYPE THE NUMBER "2" IF YOU WISH TO LOAD A
   PATHOGEN POPULATION INTO A COMPARTMENT.
1
```

```
PROVIDE SLUDGE PATHOGEN DENSITY (NUMBER OF PATHOGENS
    PER KILOGRAM (DRY WEIGHT) OF APPLIED SLUDGE)

ENTER A FORM SUCH AS 100000 OR 1E5
1E12


WHEN DOES SLUDGE APPLICATION CEASE (DAYS)?
 (FOR A SINGLE APPLICATION, ENTER "0".)
0

LAND ACCESS RESTRICTIONS VARY WITH THE CLASS
  OF SEWAGE TREATMENT.  WHAT CLASS APPLIES TO
  THIS MODEL RUN? (ENTER A, B OR C).
A


WHEN DOES THE PRACTICE BEGIN?

    MONTH (1-12):
4

    DAY (1-31):
1


WHAT IS THE LOCAL AIR TEMPERATURE RANGE?

    JANUARY AVERAGE AIR TEMP. (DEG C):   0
    JULY AVERAGE AIR TEMP. (DEG C):     30


THE DEFAULT VALUES FOR MODEL PARAMETERS
DEPEND ON THE PRACTICE AND PATHOGEN CHOSEN.


YOU HAVE CHOSEN PRACTICE           1
 AND PATHOGEN      1   SALMONELLA
PRESS RETURN TO CONTINUE
```

```
    THE CURRENT VALUES ARE:

POSITION     VARIABLE     CURRENT VALUE       CHANGED
--------     --------     -------------       BY USER

   1         ASCRS          1.00000E+12
   2         APRATE          10000.
   3         ASCIN           .00000
   4         TREG            .00000
   5         UPLIM          1.00000E+09
   6         APMETH          1.0000
   7         AREA            10.000
   8         TEMP            .00000
   9         AQUIFR          10.000
  10         POROS           .30000
  11         FILTR8          2.0000
  12         MID             10.000
  13         TRAIN          -2.0000
  14         RDEPTH          5.0000
  15         TK              .00000
  16         TIRRG           .00000
  17         IRMETH          .00000
  18         DILIRR          .00000
  19         NIRRIG          2.0000
  20         IRRATE          .50000
PRESS RETURN TO CONTINUE
```

```
POSITION      VARIABLE      CURRENT VALUE        CHANGED
________      ________      _____________        BY USER

   21         DEPTH            2.5000
   22         COUNT            .00000
   23         TWIND            60.000
   24         DWIND            6.0000
   25         WINDSP           18.000
   26         EPSMLT           .33000
   27         ESILT            .40000
   28         EHT              2.0000
   29         SCRIT            7.5000
   30         COVER            .00000
   31         AEREFF         1.00000E-03
   32         BREEZE           4.0000
   33         HT               1.6000
   34         ANDAY            345.00
   35         TMAX             30.000
   36         TMIN             .00000
   37         SLOPES         2.06000E-02
   38         NTRCPS           2.1130
   39         SLOPEP         4.49000E-03
   40         NTRCPP           1.4350
PRESS RETURN TO CONTINUE
```

```
POSITION      VARIABLE      CURRENT VALUE        CHANGED
________      ________      _____________        BY USER

   41         ASLSUR           .90000
   42         FSSUR            1.0000
   43         FRRAIN           .00000
   44         SUBSOL         5.00000E-04
   45         SUSPND         5.00000E-03
   46         FCROP1         1.00000E-08
   47         FCROP2         6.00000E-03
   48         FCROP3         1.00000E-03
   49         FCROP4         1.00000E-04
   50         FCROP5         1.20000E-02
   51         FCROP6           .00000
   52         FCROP7         2.00000E-04
   53         FRGRND         1.00000E-03
   54         SSWTCS           .00000
   55         PSTMG            .00000
   56         CSTSS            .00000
   57         SSTCS            .00000
   58         CSTSSW           .75000
   59         DTCTMT           .00000
   60         DTCTMK           .00000
PRESS RETURN TO CONTINUE
```

```
POSITION     VARIABLE     CURRENT VALUE       CHANGED
                                              BY USER
_________    _________    ______________

   61        TMTSS          .00000
   62        TMTH           .00000
   63        TMTU           .00000
   64        HTM            .00000
   65        UTM            .00000
   66        CROP           1.0000
   67        TCULT         -2.0000
   68        TCROP          720.00
   69        THARV          1800.0
   70        YIELD1        2.50000E+07
   71        YIELD2        2.50000E+07
   72        YIELD3        1.00000E+06
   73        HAY            .00000
   74        PLNT1          .00000
   75        PLNT2          .00000
   76        PLNT3          .00000
   77        PPG            .00000
   78        CATTLE         .00000
   79        COWS           .00000
   80        STORAG         .00000
PRESS RETURN TO CONTINUE
POSITION     VARIABLE     CURRENT VALUE       CHANGED
                                              BY USER
_________    _________    ______________

   81        FORAG          .00000
   82        ALFALF         .00000
   83        SCNSMP         .00000
   84        FATTEN         .00000
   85        TSLOTR         .00000
PRESS RETURN TO CONTINUE

1. TYPE THE NUMBER "1" IF YOU WISH TO ACCEPT THE
   CURRENT VALUES AND CONTINUE WITH THE PROGRAM.

2. PROVIDE P SUBSCRIPT IN THE RANGE OF 2-85
   IF YOU WISH TO CHANGE A PARAMETER OF THE MODEL.

   TYPE "99" IF YOU NEED TO SEE THE LIST AGAIN
```

(The following sequences will change the values of TCROP and THARV to 140 and 180 hours, respectively, and add one rainfall at 120 hours. In order to save space, the intermediate screen outputs listing values of the P-variables are not printed here.)

```
68

PROVIDE NEW VALUE OF THIS P

140

(68) NOW EQUALS 140.000 (OR) 1.400E+02
.
.
.

1. TYPE THE NUMBER "1" IF YOU WISH TO ACCEPT THE
   CURRENT VALUES AND CONTINUE WITH THE PROGRAM.

2. PROVIDE P SUBSCRIPT IN THE RANGE OF 2-85
   IF YOU WISH TO CHANGE A PARAMETER OF THE MODEL.

   TYPE "99" IF YOU NEED TO SEE THE LIST AGAIN

69

PROVIDE NEW VALUE OF THIS P

180

(69) NOW EQUALS 180.000 (OR) 1.800E+02
.
.
.
.

1. TYPE THE NUMBER "1" IF YOU WISH TO ACCEPT THE
   CURRENT VALUES AND CONTINUE WITH THE PROGRAM.

2. PROVIDE P SUBSCRIPT IN THE RANGE OF 2-85
   IF YOU WISH TO CHANGE A PARAMETER OF THE MODEL.

   TYPE "99" IF YOU NEED TO SEE THE LIST AGAIN

13

GIVE THE NUMBER OF RAIN EVENTS (BETWEEN 1 & 10)

GIVE START TIME (IN HRS) OF RAIN EVENT NO.  1

120

RAIN NO.  1  AT       120.00 HRS
```

```
THE PARAMETERS FOR PATHOGEN TRANSPORT BY SURFACE WATER
MAY BE OPTIONALLY CHANGED FROM THEIR DEFAULT VALUES:

        NUMBER      PARAMETER      CURRENT VALUE
          2           PDUR              2.00
          3           PTOT              5.00
          4           BTLAG              .50
          5           CN               80.00
          6           AMC               2.00
          7           STAD               .40
          8           USLEK              .40
          9           USLEL             3.00
         10           USLES              .25
         11           USLEC              .50
         12           USLEP             1.00
         13           PI                 .00
         14           WSOIL             1.33
PRESS RETURN TO CONTINUE

1. TYPE "1" TO ACCEPT THE CURRENT VALUES
   FOR RAIN NO.  1 AND PROCEED TO NEXT RAIN.

2. TYPE THE NUMBER ("2"-"14") CORRESPONDING TO THE
    PARAMETER THAT YOU WANT TO CHANGE.

1

ARE YOU DONE WITH RAIN NO.  1 ? (Y/N)  Y

THE DEFAULT VALUES FOR MODEL PARAMETERS
DEPEND ON THE PRACTICE AND PATHOGEN CHOSEN.

YOU HAVE CHOSEN PRACTICE            1
 AND PATHOGEN      1   SALMONELLA
PRESS RETURN TO CONTINUE


   THE CURRENT VALUES ARE:
```

```
POSITION    VARIABLE    CURRENT VALUE     CHANGED
                                          BY USER
   1        ASCRS        1.00000E+12
   2        APRATE       10000.
   3        ASCIN        .00000
   4        TREG         .00000
   5        UPLIM        1.00000E+09
   6        APMETH       1.0000
   7        AREA         10.000
   8        TEMP         .00000
   9        AQUIFR       10.000
  10        POROS        .30000
  11        FILTR8       2.0000
  12        MID          10.000
  13        TRAIN       -2.0000        *
  14        RDEPTH       5.0000
  15        TK           .00000
  16        TIRRG        .00000
  17        IRMETH       .00000
  18        DILIRR       .00000
  19        NIRRIG       2.0000
  20        IRRATE       .50000
PRESS RETURN TO CONTINUE
```

```
POSITION    VARIABLE    CURRENT VALUE     CHANGED
                                          BY USER
  21        DEPTH        2.5000
  22        COUNT        .00000
  23        TWIND        60.000
  24        DWIND        6.0000
  25        WINDSP       18.000
  26        EPSMLT       .33000
  27        ESILT        .40000
  28        EHT          2.0000
  29        SCRIT        7.5000
  30        COVER        .00000
  31        AEREFF       1.00000E-03
  32        BREEZE       4.0000
  33        HT           1.6000
  34        ANDAY        345.00
  35        TMAX         30.000
  36        TMIN         .00000
  37        SLOPES       2.06000E-02
  38        NTRCPS       2.1130
  39        SLOPEP       4.49000E-03
  40        NTRCPP       1.4350
PRESS RETURN TO CONTINUE
```

```
POSITION   VARIABLE   CURRENT VALUE        CHANGED
--------   --------   -------------        BY USER
   41      ASLSUR        .90000
   42      FSSUR         1.0000
   43      FRRAIN        .00000
   44      SUBSOL      5.00000E-04
   45      SUSPND      5.00000E-03
   46      FCROP1      1.00000E-08
   47      FCROP2      6.00000E-03
   48      FCROP3      1.00000E-03
   49      FCROP4      1.00000E-04
   50      FCROP5      1.20000E-02
   51      FCROP6        .00000
   52      FCROP7      2.00000E-04
   53      FRGRND      1.00000E-03
   54      SSWTCS        .00000
   55      PSTMG         .00000
   56      CSTSS         .00000
   57      SSTCS         .00000
   58      CSTSSW        .75000
   59      DTCTMT        .00000
   60      DTCTMK        .00000
PRESS RETURN TO CONTINUE
```

```
POSITION   VARIABLE   CURRENT VALUE        CHANGED
--------   --------   -------------        BY USER
   61      TMTSS         .00000
   62      TMTH          .00000
   63      TMTU          .00000
   64      HTM           .00000
   65      UTM           .00000
   66      CROP          1.0000
   67      TCULT        -2.0000
   68      TCROP         140.00       *
   69      THARV         180.00       *
   70      YIELD1      2.50000E+07
   71      YIELD2      2.50000E+07
   72      YIELD3      1.00000E+06
   73      HAY           .00000
   74      PLNT1         .00000
   75      PLNT2         .00000
   76      PLNT3         .00000
   77      PPG           .00000
   78      CATTLE        .00000
   79      COWS          .00000
   80      STORAG        .00000
PRESS RETURN TO CONTINUE
```

```
POSITION   VARIABLE   CURRENT VALUE     CHANGED
                                        BY USER
   81       FORAG         .00000
   82       ALFALF        .00000
   83       SCNSMP        .00000
   84       FATTEN        .00000
   85       TSLOTR        .00000
PRESS RETURN TO CONTINUE

1. TYPE THE NUMBER "1" IF YOU WISH TO ACCEPT THE
   CURRENT VALUES AND CONTINUE WITH THE PROGRAM.

2. PROVIDE P SUBSCRIPT IN THE RANGE OF 2-85
   IF YOU WISH TO CHANGE A PARAMETER OF THE MODEL.

   TYPE "99" IF YOU NEED TO SEE THE LIST AGAIN
1

CURRENT VALUES ACCEPTED.


OPTIONAL GROWTH OR INACTIVATION RATES MAY BE ENTERED
TO REPLACE THE DEFAULT VALUES (SEE THE USER MANUAL
FOR A DESCRIPTION OF THE DEFAULT CONDITIONS).
  1. ACCEPT VALUES

                                 CURRENT VALUE
  2. PROC1 - MOIST SOIL            -5.000000

  3. PROC2 - DRY PARTICULATES -5.000000

  4. PROC3 - WATER SUSPENSION -5.000000

  5. HCRIT - DROPLET AEROSOL  -2.800000E-02

IF YOU WISH TO CHANGE THE VALUE OF A VARIABLE, ENTER
THE NUMBER.  TO ACCEPT THE CURRENT VALUES, ENTER "1".
1

CURRENT VALUES ACCEPTED.
```

```
THE INFECTION RISK PARAMETERS LISTED BELOW MAY BE
OPTIONALLY CHANGED FROM THEIR DEFAULT VALUES.

NUMBER  PARAMETER  VALUE       NUMBER  PARAMETER    VALUE
   2     COOKA      .000         19      PASTP        .001
   3     COOKP      .000         20      TEMI2       4.000
   4     COOKS      .000         21      TEMI4       4.000
   5     DRECTC     .100         22      TEMP2       7.000
   6     DRECTS     .100         23      TEMP4        .000
   7     IBLAN      .000         24      TMIS2      24.000
   8     ICAN       .000         25      TMIS4      24.000
   9     ICANG      .000         26      TMP2M       4.000
  10     ICOOK      .000         27      TMP7F      -4.000
  11     IFREE      .000         28      TMP7N      20.000
  12     IFREG      .000         29      TSTM2     720.000
  13     IPAST      .000         30      TSTR2     168.000
  14     ISTRH     1.000         31      TSTR4     120.000
  15     ISTRP      .000         32      TSTR7     720.000
  16     IWASH     1.000         33      VOLPND    100.000
  17     PASTB      .000         34      XDIST     200.000
  18     PASTA      .001         35      YDIST        .000
PRESS RETURN TO CONTINUE

1. TYPE "1" TO ACCEPT THE CURRENT VALUES
   AND CONTINUE WITH THE PROGRAM.

2. TYPE THE NUMBER ("2" - "35") CORRESPONDING TO
   THE PARAMETER THAT YOU WISH TO CHANGE.

1
```

```
************************************************************************
TEST
************************************************************************


  PRACTICE STOP TIME=       20 DAYS
  PRINT SAMPLING RATE (IPRNT) =     8 HOURS
  PRACTICE NUMBER =    1
  PATHOGEN =   1 SALMONELLA
  NUMBER OF COMPARTMENTS THIS PRACTICE =   16
  INITIAL POPULATIONS FOR COMPARTMENTS:
       COMPARTMENT  1 =   0.0000E+00
       COMPARTMENT  2 =   0.0000E+00
       COMPARTMENT  3 =   0.0000E+00
       COMPARTMENT  4 =   0.0000E+00
       COMPARTMENT  5 =   0.0000E+00
       COMPARTMENT  6 =   0.0000E+00
       COMPARTMENT  7 =   0.0000E+00
       COMPARTMENT  8 =   0.0000E+00
       COMPARTMENT  9 =   0.0000E+00
       COMPARTMENT 10 =   0.0000E+00
       COMPARTMENT 11 =   0.0000E+00
       COMPARTMENT 12 =   0.0000E+00
       COMPARTMENT 13 =   0.0000E+00
       COMPARTMENT 14 =   0.0000E+00
       COMPARTMENT 15 =   0.0000E+00
       COMPARTMENT 16 =   0.0000E+00
 SLUDGE PATHOGEN DENSITY =    1.0000E+12 NUMBER/KG
PRESS RETURN TO CONTINUE


THERE ARE   1 RAIN EVENTS WHICH OCCUR AT:
  I     TRAIN(I) [Hrs]
  1     120.00

THESE PARAMETERS HAVE BEEN CHANGED:
    P(68) NOW EQUALS             140.000 (OR)   1.400E+02
    P(69) NOW EQUALS             180.000 (OR)   1.800E+02
```

```
THE PARAMETERS FOR PREDICTING VIRAL AND BACTERIAL
TRANSPORT IN GROUNDWATER AFTER LAND APPLICATION OF
SEWAGE SLUDGE MAY BE OPTIONALLY CHANGED FROM THEIR
DEFAULT VALUES.

NUMBER     PARAMETER       CURRENT VALUE
  2            V
  3            D                  3.600
  4            R                 60.000
  5            DZERO              1.000
  6            DONE                .000
  7            DBND                .000
  8            ALPHA               .000
  9            XI                  .012
 10            DX                50.000
 11            XM                50.000
 12            DT                50.000
       PRESS RETURN TO CONTINUE   1.000

 1. TYPE "1" TO ACCEPT THE CURRENT VALUES.

 2. TYPE THE NUMBER ("2"-"12") CORRESPONDING TO THE
    PARAMETER THAT YOU WANT TO CHANGE.
9

PROVIDE NEW VALUE INITIAL X - XI (M).
TYPE "-10" TO KEEP PARAMETER UNALTERED.
12
```

(Variable 10 is changed to 1, and variable 11 is changed to 12 to cause the following output:)

```
THE PARAMETERS FOR PREDICTING VIRAL AND BACTERIAL
TRANSPORT IN GROUNDWATER AFTER LAND APPLICATION OF
SEWAGE SLUDGE MAY BE OPTIONALLY CHANGED FROM THEIR
DEFAULT VALUES.

NUMBER     PARAMETER       CURRENT VALUE
  2            V
  3            D                  3.600
  4            R                 60.000
  5            DZERO              1.000
  6            DONE                .000
  7            DBND                .000
  8            ALPHA               .000
  9            XI                  .012
 10            DX                12.000
 11            XM                 1.000
 12            DT                12.000
PRESS RETURN TO CONTINUE          1.000
```

```
1. TYPE "1" TO ACCEPT THE CURRENT VALUES.

2. TYPE THE NUMBER ("2"-"12") CORRESPONDING TO THE
   PARAMETER THAT YOU WANT TO CHANGE.
1


RUNNING . . .
```

6.2. INFECTION PROBABILITIES

The following table will appear both on the screen and in a file entitled SAMPLE1:

```
                     ----------PROBABILITY OF INFECTION----------
DAY  ONSITE       OFFSITE      EATER        DRINKER      SWIMMER

 1   0.000E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
 2   1.000E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
 3   1.000E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
 4   1.000E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
 5   1.000E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
 6   1.000E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
 7   1.000E+00    0.000E+00    0.000E+00    0.000E+00    1.000E+00
 8   1.000E+00    0.000E+00    0.000E+00    0.000E+00    1.000E+00
 9   1.000E+00    0.000E+00    0.000E+00    0.000E+00    1.000E+00
10   1.000E+00    0.000E+00    3.363E-04    2.220E-16    1.000E+00
11   9.889E-01    0.000E+00    0.000E+00    0.000E+00    1.000E+00
12   3.994E-02    0.000E+00    0.000E+00    0.000E+00    1.000E+00
13   2.885E-06    0.000E+00    0.000E+00    0.000E+00    1.000E+00
14   1.677E-11    0.000E+00    0.000E+00    7.183E-14    1.000E+00
15   2.220E-16    0.000E+00    0.000E+00    1.093E-11    1.000E+00
16   1.110E-16    0.000E+00    0.000E+00    1.079E-10    1.000E+00
17   0.000E+00    0.000E+00    0.000E+00    1.305E-10    1.000E+00
18   0.000E+00    0.000E+00    0.000E+00    3.828E-11    1.000E+00
19   0.000E+00    0.000E+00    0.000E+00    6.130E-12    1.000E+00
20   0.000E+00    0.000E+00    0.000E+00    1.208E-12    1.000E+00
                                            3.961E-13    1.000E+00
```

6.3. CONTENTS OF COMPARTMENTS

A report showing the number of pathogens in each compartment of the model at the reporting interval specified via the menu is given in a file named PATHOUT:

```
*****************************************************************

TEST

*****************************************************************


 PRACTICE STOP TIME=        20 DAYS
 PRINT SAMPLING RATE - IPRNT =     8 HOURS
 PRACTICE NUMBER =    1
 PATHOGEN =   1 SALMONELLA
 NUMBER OF COMPARTMENTS THIS PRACTICE =   16
 INITIAL POPULATIONS FOR COMPARTMENTS:
     COMPARTMENT  1 =   0.0000E+00
     COMPARTMENT  2 =   0.0000E+00
     COMPARTMENT  3 =   0.0000E+00
     COMPARTMENT  4 =   0.0000E+00
     COMPARTMENT  5 =   0.0000E+00
     COMPARTMENT  6 =   0.0000E+00
     COMPARTMENT  7 =   0.0000E+00
     COMPARTMENT  8 =   0.0000E+00
     COMPARTMENT  9 =   0.0000E+00
     COMPARTMENT 10 =   0.0000E+00
     COMPARTMENT 11 =   0.0000E+00
     COMPARTMENT 12 =   0.0000E+00
     COMPARTMENT 13 =   0.0000E+00
     COMPARTMENT 14 =   0.0000E+00
     COMPARTMENT 15 =   0.0000E+00
     COMPARTMENT 16 =   0.0000E+00
 SLUDGE PATHOGEN DENSITY =    1.0000E+12 NUMBER/KG

THERE ARE  1 RAIN EVENTS WHICH OCCUR AT:
 I     TRAIN(I) [Hrs]
 1     120.00

THESE PARAMETERS HAVE BEEN CHANGED:
    P(68) NOW EQUALS              140.000 (OR)  1.400E+02
    P(69) NOW EQUALS              180.000 (OR)  1.800E+02
```

```
HOUR   8   7.208E+15  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR  16   4.958E+15  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR  24   3.411E+15  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                =   0.000000E+00
OFFSITE PERSON INFECTION PROBABILITY               =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY          =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY                 =   0.000000E+00

HOUR  32   0.000E+00  0.000E+00  0.000E+00  2.568E+15  0.000E+00  0.000E+00
           4.487E+04  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR  40   0.000E+00  0.000E+00  0.000E+00  1.758E+15  0.000E+00  0.000E+00
           3.072E+04  9.396E+11  1.001E+09  1.014E+09  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR  48   0.000E+00  0.000E+00  0.000E+00  1.204E+15  0.000E+00  0.000E+00
           1.052E+04  6.971E+11  9.092E+08  9.203E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                =      1.000000
OFFSITE PERSON INFECTION PROBABILITY               =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY          =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY                 =   0.000000E+00

HOUR  56   0.000E+00  0.000E+00  0.000E+00  8.210E+14  0.000E+00  0.000E+00
           1.435E+04  5.154E+11  8.256E+08  8.356E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR  64   0.000E+00  0.000E+00  0.000E+00  5.598E+14  0.000E+00  0.000E+00
           9.788E+03  3.810E+11  7.496E+08  7.587E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR  72   0.000E+00  0.000E+00  0.000E+00  3.817E+14  0.000E+00  0.000E+00
           3.337E+03  2.817E+11  6.806E+08  6.889E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                =      1.000000
OFFSITE PERSON INFECTION PROBABILITY               =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY          =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY                 =   0.000000E+00
```

```
HOUR  80   0.000E+00  0.000E+00  0.000E+00  2.591E+14  0.000E+00  0.000E+00
           4.533E+03  2.075E+11  6.180E+08  6.255E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR  88   0.000E+00  0.000E+00  0.000E+00  1.750E+14  0.000E+00  0.000E+00
           3.061E+03  1.529E+11  5.612E+08  5.670E+08  9.573E+11  0.000E+00
           9.466E+02  0.000E+00  0.000E+00  0.000E+00

HOUR  96   0.000E+00  0.000E+00  0.000E+00  1.188E+14  0.000E+00  0.000E+00
           1.039E+03  1.126E+11  5.095E+08  5.157E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY              =        1.000000
OFFSITE PERSON INFECTION PROBABILITY             =     0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY              =     0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY        =     0.000000E+00
POND SWIMMER INFECTION PROBABILITY               =     0.000000E+00

HOUR 104   0.000E+00  0.000E+00  0.000E+00  8.026E+13  0.000E+00  0.000E+00
           1.405E+03  8.266E+10  4.626E+08  4.683E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 112   0.000E+00  0.000E+00  0.000E+00  5.423E+13  0.000E+00  0.000E+00
           9.492E+02  6.067E+10  4.201E+08  4.252E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 120   0.000E+00  0.000E+00  0.000E+00  3.664E+13  0.000E+00  0.000E+00
           3.207E+02  4.453E+10  3.814E+08  3.861E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY              =        1.000000
OFFSITE PERSON INFECTION PROBABILITY             =     0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY              =     0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY        =     0.000000E+00
POND SWIMMER INFECTION PROBABILITY               =     0.000000E+00

HOUR 128   0.000E+00  0.000E+00  0.000E+00  2.421E+13  0.000E+00  5.454E+10
           4.241E+02  3.257E+10  3.463E+08  3.505E+08  1.467E+11  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 136   0.000E+00  0.000E+00  0.000E+00  1.628E+13  0.000E+00  4.952E+10
           2.851E+02  3.280E+10  3.525E+08  3.568E+08  1.332E+11  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 144   0.000E+00  0.000E+00  0.000E+00  1.095E+13  0.000E+00  4.497E+10
           9.587E+01  2.399E+10  3.201E+08  3.240E+08  1.210E+11  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY              =        1.000000
OFFSITE PERSON INFECTION PROBABILITY             =     0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY              =     0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY        =     0.000000E+00
POND SWIMMER INFECTION PROBABILITY               =        1.000000
```

```
HOUR  80   0.000E+00  0.000E+00  0.000E+00  2.591E+14  0.000E+00  0.000E+00
           4.533E+03  2.075E+11  6.180E+08  6.255E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR  88   0.000E+00  0.000E+00  0.000E+00  1.750E+14  0.000E+00  0.000E+00
           3.061E+03  1.529E+11  5.612E+08  5.670E+08  9.573E+11  0.000E+00
           9.466E+02  0.000E+00  0.000E+00  0.000E+00

HOUR  96   0.000E+00  0.000E+00  0.000E+00  1.188E+14  0.000E+00  0.000E+00
           1.039E+03  1.126E+11  5.095E+08  5.157E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY             =      1.000000
OFFSITE PERSON INFECTION PROBABILITY            =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY             =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY       =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY              =   0.000000E+00

HOUR 104   0.000E+00  0.000E+00  0.000E+00  8.026E+13  0.000E+00  0.000E+00
           1.405E+03  8.266E+10  4.626E+08  4.683E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 112   0.000E+00  0.000E+00  0.000E+00  5.423E+13  0.000E+00  0.000E+00
           9.492E+02  6.067E+10  4.201E+08  4.252E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 120   0.000E+00  0.000E+00  0.000E+00  3.664E+13  0.000E+00  0.000E+00
           3.207E+02  4.453E+10  3.814E+08  3.861E+08  0.000E+00  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY             =      1.000000
OFFSITE PERSON INFECTION PROBABILITY            =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY             =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY       =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY              =   0.000000E+00

HOUR 128   0.000E+00  0.000E+00  0.000E+00  2.421E+13  0.000E+00  5.454E+10
           4.241E+02  3.257E+10  3.463E+08  3.505E+08  1.467E+11  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 136   0.000E+00  0.000E+00  0.000E+00  1.628E+13  0.000E+00  4.952E+10
           2.851E+02  3.280E+10  3.525E+08  3.568E+08  1.332E+11  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 144   0.000E+00  0.000E+00  0.000E+00  1.095E+13  0.000E+00  4.497E+10
           9.587E+01  2.399E+10  3.201E+08  3.240E+08  1.210E+11  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY             =      1.000000
OFFSITE PERSON INFECTION PROBABILITY            =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY             =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY       =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY              =      1.000000
```

```
HOUR 152   0.000E+00  0.000E+00  0.000E+00  7.328E+12  0.000E+00  4.083E+10
           1.284E+02  1.748E+10  2.906E+08  2.942E+08  1.099E+11  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 160   0.000E+00  0.000E+00  0.000E+00  4.906E+12  0.000E+00  3.707E+10
           8.597E+01  1.273E+10  2.639E+08  2.671E+08  9.975E+10  0.000E+00
           0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 168   0.000E+00  0.000E+00  0.000E+00  3.284E+12  0.000E+00  3.366E+10
           2.877E+01  9.278E+09  2.396E+08  2.425E+08  9.057E+10  4.955E+04
           0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                 =         1.000000
OFFSITE PERSON INFECTION PROBABILITY                =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                 =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY           =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY                  =         1.000000

HOUR 176   0.000E+00  0.000E+00  0.000E+00  2.176E+12  0.000E+00  3.056E+10
           3.816E+01  6.734E+09  2.176E+08  2.202E+08  0.000E+00  3.127E+01
           0.000E+00  9.739E+06  0.000E+00  0.000E+00

HOUR 184   0.000E+00  0.000E+00  0.000E+00  1.450E+12  0.000E+00  2.775E+10
           2.542E+01  4.888E+09  1.975E+08  1.999E+08  0.000E+00  3.127E+01
           0.000E+00  0.000E+00  7.910E+06  0.000E+00

HOUR 192   0.000E+00  0.000E+00  0.000E+00  9.657E+11  0.000E+00  2.520E+10
           8.467E+00  3.548E+09  1.794E+08  1.815E+08  0.000E+00  3.127E+01
           0.000E+00  0.000E+00  4.021E+07  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                 =         1.000000
OFFSITE PERSON INFECTION PROBABILITY                =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                 =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY           =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY                  =         1.000000

HOUR 200   0.000E+00  0.000E+00  0.000E+00  6.402E+11  0.000E+00  2.288E+10
           1.123E+01  2.565E+09  1.629E+08  1.648E+08  0.000E+00  2.289E+03
           0.000E+00  0.000E+00  8.042E+06  0.000E+00
                PPG PRIOR TO PROCESSING =   3.164146E-01
                PPG AFTER PROCESSING    =   3.164146E-02

HOUR 208   0.000E+00  0.000E+00  0.000E+00  4.242E+11  0.000E+00  2.078E+10
           7.443E+00  2.081E+09  1.501E+08  1.519E+08  0.000E+00  8.275E+04
           0.000E+00  0.000E+00  0.000E+00  8.042E+06

HOUR 216   0.000E+00  0.000E+00  0.000E+00  2.812E+11  0.000E+00  1.886E+10
           2.467E+00  1.505E+09  1.363E+08  1.380E+08  0.000E+00  8.275E+04
           0.000E+00  0.000E+00  0.000E+00  8.042E+06
ONSITE PERSON INFECTION PROBABILITY                 =         1.000000
OFFSITE PERSON INFECTION PROBABILITY                =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                 =   3.363204E-04
GROUNDWATER DRINKER INFECTION PROBABILITY           =   2.220446E-16
POND SWIMMER INFECTION PROBABILITY                  =         1.000000
```

```
HOUR 224    0.000E+00  0.000E+00  0.000E+00  1.855E+11  0.000E+00  1.713E+10
            3.257E+00  1.084E+09  1.238E+08  1.253E+08  0.000E+00  4.418E+04
            0.000E+00  0.000E+00  0.000E+00  8.042E+06

HOUR 232    0.000E+00  0.000E+00  0.000E+00  1.224E+11  0.000E+00  1.555E+10
            2.148E+00  7.804E+08  1.124E+08  1.137E+08  0.000E+00  4.418E+04
            0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 240    0.000E+00  0.000E+00  0.000E+00  8.072E+10  0.000E+00  1.412E+10
            7.085E-01  5.621E+08  1.020E+08  1.033E+08  0.000E+00  4.418E+04
            0.000E+00  0.000E+00  0.000E+00  0.000E+00
ONSITE PERSON INFECTION PROBABILITY               =      1.000000
OFFSITE PERSON INFECTION PROBABILITY              =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY               =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY         =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY                =      1.000000

HOUR 248    0.000E+00  0.000E+00  0.000E+00  5.298E+10  0.000E+00  1.282E+10
            9.307E-01  4.032E+08  9.264E+07  9.377E+07  0.000E+00  3.410E+05
            0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 256    0.000E+00  0.000E+00  0.000E+00  3.459E+10  0.000E+00  1.164E+10
            6.076E-01  2.892E+08  8.412E+07  8.514E+07  1.908E+08  3.410E+05
            0.000E+00  0.000E+00  0.000E+00  0.000E+00

HOUR 264    0.000E+00  0.000E+00  0.000E+00  2.270E+10  0.000E+00  1.057E+10
            1.994E-01  2.075E+08  7.638E+07  7.731E+07  0.000E+00  3.410E+05
            0.000E+00  0.000E+00  1.840E+04  0.000E+00
ONSITE PERSON INFECTION PROBABILITY               =   9.888999E-01
OFFSITE PERSON INFECTION PROBABILITY              =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY               =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY         =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY                =      1.000000

HOUR 272    0.000E+00  0.000E+00  0.000E+00  1.482E+10  0.000E+00  9.598E+09
            2.606E-01  1.482E+08  6.935E+07  7.019E+07  0.000E+00  1.361E+06
            0.000E+00  0.000E+00  1.840E+04  0.000E+00

HOUR 280    0.000E+00  0.000E+00  0.000E+00  9.679E+09  0.000E+00  8.715E+09
            1.701E-01  1.059E+08  6.297E+07  6.374E+07  0.000E+00  1.361E+06
            0.000E+00  0.000E+00  1.840E+04  0.000E+00

HOUR 288    0.000E+00  0.000E+00  0.000E+00  6.320E+09  0.000E+00  7.913E+09
            5.555E-02  7.567E+07  5.718E+07  5.787E+07  0.000E+00  1.361E+06
            0.000E+00  0.000E+00  1.840E+04  0.000E+00
ONSITE PERSON INFECTION PROBABILITY               =   3.994424E-02
OFFSITE PERSON INFECTION PROBABILITY              =   0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY               =   0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY         =   0.000000E+00
POND SWIMMER INFECTION PROBABILITY                =      1.000000
```

```
HOUR 296   0.000E+00  0.000E+00  0.000E+00  4.103E+09  0.000E+00  7.185E+09
           7.218E-02  5.611E+07  5.199E+07  5.262E+07  0.000E+00  3.363E+06
           0.000E+00  0.000E+00  1.840E+04  0.000E+00

HOUR 304   0.000E+00  0.000E+00  0.000E+00  2.665E+09  0.000E+00  6.524E+09
           4.689E-02  3.992E+07  4.720E+07  4.777E+07  0.000E+00  3.363E+06
           0.000E+00  0.000E+00  1.840E+04  0.000E+00

HOUR 312   0.000E+00  0.000E+00  0.000E+00  1.731E+09  0.000E+00  5.924E+09
           1.523E-02  2.841E+07  4.286E+07  4.338E+07  0.000E+00  3.363E+06
           0.000E+00  0.000E+00  1.840E+04  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                  =  2.884822E-06
OFFSITE PERSON INFECTION PROBABILITY                 =  0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                  =  0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY            =  7.183143E-14
POND SWIMMER INFECTION PROBABILITY                   =      1.000000

HOUR 320   0.000E+00  0.000E+00  0.000E+00  1.119E+09  0.000E+00  5.379E+09
           1.969E-02  2.013E+07  3.892E+07  3.939E+07  0.000E+00  5.633E+06
           0.000E+00  0.000E+00  1.840E+04  0.000E+00

HOUR 328   0.000E+00  0.000E+00  0.000E+00  7.230E+08  0.000E+00  4.884E+09
           1.273E-02  1.426E+07  3.534E+07  3.576E+07  0.000E+00  5.633E+06
           0.000E+00  0.000E+00  1.840E+04  0.000E+00

HOUR 336   0.000E+00  0.000E+00  0.000E+00  4.672E+08  0.000E+00  4.435E+09
           4.111E-03  1.011E+07  3.208E+07  3.247E+07  0.000E+00  5.633E+06
           0.000E+00  0.000E+00  1.840E+04  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                  =  1.676737E-11
OFFSITE PERSON INFECTION PROBABILITY                 =  0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                  =  0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY            =  1.093226E-11
POND SWIMMER INFECTION PROBABILITY                   =      1.000000

HOUR 344   0.000E+00  0.000E+00  0.000E+00  2.987E+08  0.000E+00  4.027E+09
           5.261E-03  7.131E+06  2.913E+07  2.949E+07  0.000E+00  7.147E+06
           0.000E+00  1.993E+02  1.840E+04  0.000E+00

HOUR 352   0.000E+00  0.000E+00  0.000E+00  1.920E+08  0.000E+00  3.656E+09
           3.381E-03  5.032E+06  2.645E+07  2.677E+07  0.000E+00  7.147E+06
           0.000E+00  0.000E+00  1.860E+04  0.000E+00

HOUR 360   0.000E+00  0.000E+00  0.000E+00  1.234E+08  0.000E+00  3.320E+09
           1.087E-03  3.550E+06  2.402E+07  2.431E+07  0.000E+00  7.147E+06
           0.000E+00  0.000E+00  1.860E+04  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                  =  2.220446E-16
OFFSITE PERSON INFECTION PROBABILITY                 =  0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                  =  0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY            =  1.078816E-10
POND SWIMMER INFECTION PROBABILITY                   =      1.000000
```

```
HOUR 368   0.000E+00  0.000E+00  0.000E+00  7.887E+07  0.000E+00  3.014E+09
           1.390E-03  2.494E+06  2.181E+07  2.207E+07  0.000E+00  7.291E+06
           0.000E+00  0.000E+00  1.860E+04  0.000E+00
HOUR 376   0.000E+00  0.000E+00  0.000E+00  5.039E+07  0.000E+00  2.737E+09
           8.882E-04  1.778E+06  1.980E+07  2.004E+07  0.000E+00  7.291E+06
           0.000E+00  0.000E+00  1.860E+04  0.000E+00
HOUR 384   0.000E+00  0.000E+00  0.000E+00  3.221E+07  0.000E+00  2.485E+09
           2.839E-04  1.249E+06  1.798E+07  1.820E+07  0.000E+00  7.291E+06
           0.000E+00  0.000E+00  1.860E+04  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                    =  1.110223E-16
OFFSITE PERSON INFECTION PROBABILITY                   =  0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                    =  0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY              =  1.305227E-10
POND SWIMMER INFECTION PROBABILITY                     =        1.000000
HOUR 392   0.000E+00  0.000E+00  0.000E+00  2.048E+07  0.000E+00  2.256E+09
           3.612E-04  8.739E+05  1.633E+07  1.652E+07  0.000E+00  6.415E+06
           0.000E+00  0.000E+00  1.860E+04  0.000E+00
HOUR 400   0.000E+00  0.000E+00  0.000E+00  1.302E+07  0.000E+00  2.049E+09
           2.296E-04  6.113E+05  1.482E+07  1.500E+07  0.000E+00  6.415E+06
           0.000E+00  0.000E+00  1.860E+04  0.000E+00
HOUR 408   0.000E+00  0.000E+00  0.000E+00  8.278E+06  0.000E+00  1.860E+09
           7.300E-05  4.277E+05  1.346E+07  1.362E+07  0.000E+00  6.415E+06
           0.000E+00  0.000E+00  1.860E+04  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                    =  0.000000E+00
OFFSITE PERSON INFECTION PROBABILITY                   =  0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                    =  0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY              =  3.828304E-11
POND SWIMMER INFECTION PROBABILITY                     =        1.000000
HOUR 416   0.000E+00  0.000E+00  0.000E+00  5.233E+06  0.000E+00  1.689E+09
           9.237E-05  2.979E+05  1.222E+07  1.237E+07  0.000E+00  5.306E+06
           0.000E+00  0.000E+00  1.860E+04  0.000E+00
HOUR 424   0.000E+00  0.000E+00  0.000E+00  3.291E+06  0.000E+00  1.534E+09
           5.809E-05  2.075E+05  1.110E+07  1.121E+07  5.199E+04  5.306E+06
           1.872E+01  1.765E+03  1.861E+04  0.000E+00
HOUR 432   0.000E+00  0.000E+00  0.000E+00  2.081E+06  0.000E+00  1.393E+09
           1.836E-05  1.445E+05  1.008E+07  1.020E+07  0.000E+00  5.306E+06
           0.000E+00  0.000E+00  1.861E+04  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                    =  0.000000E+00
OFFSITE PERSON INFECTION PROBABILITY                   =  0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                    =  0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY              =  6.130429E-12
POND SWIMMER INFECTION PROBABILITY                     =        1.000000
```

```
HOUR 440   0.000E+00  0.000E+00  0.000E+00  1.308E+06  0.000E+00  1.264E+09
           2.310E-05  1.002E+05  9.149E+06  9.260E+06  0.000E+00  4.488E+06
           0.000E+00  0.000E+00  1.861E+04  0.000E+00

HOUR 448   0.000E+00  0.000E+00  0.000E+00  8.223E+05  0.000E+00  1.148E+09
           1.452E-05  6.947E+04  8.308E+06  8.408E+06  0.000E+00  4.488E+06
           0.000E+00  0.000E+00  1.861E+04  0.000E+00

HOUR 456   0.000E+00  0.000E+00  0.000E+00  5.169E+05  0.000E+00  1.042E+09
           4.565E-06  4.817E+04  7.543E+06  7.635E+06  0.000E+00  4.488E+06
           0.000E+00  0.000E+00  1.861E+04  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                  =  0.000000E+00
OFFSITE PERSON INFECTION PROBABILITY                 =  0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                  =  0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY            =  1.207590E-12
POND SWIMMER INFECTION PROBABILITY                   =      1.000000

HOUR 464   0.000E+00  0.000E+00  0.000E+00  3.230E+05  0.000E+00  9.466E+08
           5.708E-06  3.340E+04  6.849E+06  6.932E+06  0.000E+00  4.003E+06
           0.000E+00  0.000E+00  1.861E+04  0.000E+00

HOUR 472   0.000E+00  0.000E+00  0.000E+00  2.019E+05  0.000E+00  8.595E+08
           3.568E-06  2.305E+04  6.219E+06  6.294E+06  0.000E+00  4.003E+06
           0.000E+00  0.000E+00  1.861E+04  0.000E+00

HOUR 480   0.000E+00  0.000E+00  0.000E+00  1.262E+05  0.000E+00  7.804E+08
           1.115E-06  1.591E+04  5.647E+06  5.715E+06  0.000E+00  4.003E+06
           0.000E+00  0.000E+00  1.861E+04  0.000E+00
ONSITE PERSON INFECTION PROBABILITY                  =  0.000000E+00
OFFSITE PERSON INFECTION PROBABILITY                 =  0.000000E+00
FOOD CONSUMER INFECTION PROBABILITY                  =  0.000000E+00
GROUNDWATER DRINKER INFECTION PROBABILITY            =  3.961276E-13
POND SWIMMER INFECTION PROBABILITY                   =      1.000000
```

6.4. SURFACE RUNOFF AND SEDIMENT TRANSPORT

Output from Subroutine RAINS is found in the file RAINS:

```
RAIN EVENT NO.  1    STARTING AT 120.00  HRS

 1. ANTECEDENT MOISTURE (AMC)        =     2 (-)
 2. AREA                             =     1.00E+01 (HECTARE)
 3. AREA (AREAK)                     =     1.00E-01 (KM**2)
 4. BASIN TIME LAG (BTLAG)           =     5.00E-01 (HRS)
 5. CURVE NUMBER (CN)                =     8.00E+01 (-)
 6. RAIN DURATION (PDUR)             =     2.00E+00 (HRS)
 7. PI                               =     5.00E-03 (-)
 8. TOTAL RAIN (PTOT)                =     5.00E+00 (CM)
 9. STORM ADVANCEMENT (STAD)         =     4.00E-01 (-)
10. USLEC                            =     5.00E-01 (-)
11. USLEK                            =     4.00E-01 (-)
12. USLEL                            =     3.00E+00 (-)
13. USLES                            =     2.50E-01 (-)
14. USLEP                            =     1.00E+00 (-)
15. SOIL BULK DENSITY (WSOIL)        =     1.33E+00 (G/CC)
```

```
HYETOGRAPH DPE(MM)

      1             2             3             4             5             6             7             8
3.125000E-02  9.375001E-02  1.562500E-01  2.187500E-01  2.481856E-01  2.086702E-01  1.670035E-01  1.253369E-01

      9            10            11
8.367018E-02  4.200352E-02  5.378120E-03


SCS UNIT HYDROGRAPH U(KK)

      1             2             3             4             5             6             7             8
6.876033E-02  1.375207E-01  2.062810E-01  2.750413E-01  3.438016E-01  3.575948E-01  3.164210E-01  2.752472E-01

      9            10            11            12            13            14
2.340733E-01  1.928995E-01  1.517256E-01  1.105518E-01  6.937797E-02  2.820411E-02
```

QMAT(NN,MM)

	1	2	3	4	5	6	7	8
1	2.148760E-03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
2	4.297520E-03	6.446281E-03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
3	6.446281E-03	1.289256E-02	1.074380E-02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
4	8.595041E-03	1.933884E-02	2.148760E-02	1.504132E-02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
5	1.074380E-02	2.578513E-02	3.223140E-02	3.008264E-02	1.706532E-02	0.000000E+00	0.000000E+00	0.000000E+00
6	1.117484E-02	3.223141E-02	4.297521E-02	4.512396E-02	3.413064E-02	1.434823E-02	0.000000E+00	0.000000E+00
7	9.888157E-03	3.352452E-02	5.371900E-02	6.016529E-02	5.119596E-02	2.869646E-02	1.148322E-02	0.000000E+00
8	8.601474E-03	2.966447E-02	5.587419E-02	7.520661E-02	6.826129E-02	4.304469E-02	2.296643E-02	8.618203E-03
9	7.314791E-03	2.580442E-02	4.944079E-02	7.822387E-02	8.532660E-02	5.739292E-02	3.444964E-02	1.723641E-02
10	6.028109E-03	2.194438E-02	4.300737E-02	6.921710E-02	8.874989E-02	7.174114E-02	4.593286E-02	2.585461E-02
11	4.741426E-03	1.808433E-02	3.657396E-02	6.021032E-02	7.853114E-02	7.461938E-02	5.741607E-02	3.447281E-02
12	3.454743E-03	1.422428E-02	3.014055E-02	5.120354E-02	6.831238E-02	6.602763E-02	5.971959E-02	4.309101E-02
13	2.168062E-03	1.036423E-02	2.370713E-02	4.219677E-02	5.809363E-02	5.743587E-02	5.284342E-02	4.481981E-02
14	8.813785E-04	6.504185E-03	1.727371E-02	3.318998E-02	4.787488E-02	4.884412E-02	4.596724E-02	3.965922E-02
15	0.000000E+00	2.644136E-03	1.084031E-02	2.418320E-02	3.765612E-02	4.025237E-02	3.909107E-02	3.449861E-02
16	0.000000E+00	0.000000E+00	4.406892E-03	1.517643E-02	2.743736E-02	3.166061E-02	3.221489E-02	2.933802E-02
17	0.000000E+00	0.000000E+00	0.000000E+00	6.169649E-03	1.721861E-02	2.306886E-02	2.533871E-02	2.417742E-02
18	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	6.999854E-03	1.447711E-02	1.846253E-02	1.901681E-02
19	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	5.885357E-03	1.158636E-02	1.385621E-02
20	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.710185E-03	8.695617E-03
21	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	3.535015E-03
22	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
23	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
24	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00

	9	10	11
1	0.000000E+00	0.000000E+00	0.000000E+00
2	0.000000E+00	0.000000E+00	0.000000E+00
3	0.000000E+00	0.000000E+00	0.000000E+00
4	0.000000E+00	0.000000E+00	0.000000E+00
5	0.000000E+00	0.000000E+00	0.000000E+00
6	0.000000E+00	0.000000E+00	0.000000E+00
7	0.000000E+00	0.000000E+00	0.000000E+00
8	0.000000E+00	0.000000E+00	0.000000E+00
9	5.753189E-03	0.000000E+00	0.000000E+00
10	1.150638E-02	2.888176E-03	0.000000E+00
11	1.725957E-02	5.776352E-03	3.698013E-04
12	2.301276E-02	8.664528E-03	7.396025E-04
13	2.876594E-02	1.155270E-02	1.109404E-03
14	2.992002E-02	1.444088E-02	1.479205E-03
15	2.647500E-02	1.502024E-02	1.849006E-03
16	2.302998E-02	1.329080E-02	1.923188E-03
17	1.958496E-02	1.156135E-02	1.701750E-03
18	1.613994E-02	9.831904E-03	1.480312E-03
19	1.269491E-02	8.102459E-03	1.258874E-03
20	9.249886E-03	6.373012E-03	1.037437E-03
21	5.804867E-03	4.643564E-03	8.159986E-04
22	2.359843E-03	2.914119E-03	5.945607E-04
23	0.000000E+00	1.184672E-03	3.731230E-04
24	0.000000E+00	0.000000E+00	1.516851E-04

```
CONVOLUTION INTEGRAL Q(NN)

      1            2            3            4            5            6            7            8

2.148760E-03 1.074380E-02 3.008264E-02 6.446281E-02 1.159083E-01 1.799843E-01 2.486726E-01 3.122374E-01

      9           10           11           12           13           14           15           16

3.609426E-01 3.868700E-01 3.880551E-01 3.685906E-01 3.330570E-01 2.860348E-01 2.325101E-01 1.784782E-01

     17           18           19           20           21           22           23           24

1.288213E-01 8.640847E-02 5.338418E-02 3.006614E-02 1.479944E-02 5.868523E-03 1.557795E-03 1.516851E-04

QTOTAL =   3.820


L =  1   TAUR =  1.3802E-03   TAUS =  3.4195E-04   TAU(L) =  1.7222E-03


QTOTH - VECTOR

      1            2            3
1.712053E+00 2.085406E+00 2.237745E-02
```

```
QMAXH - VECTOR

        1              2              3
  3.868700E-01   3.880551E-01   1.479944E-02

L = 1   I =   1  TAURH =  6.1863E-04  TAUSH =  1.6032E-04  TAU(I,L) =  7.7895E-04

L = 1   I =   2  TAURH =  7.5353E-04  TAUSH =  1.7936E-04  TAU(I,L) =  9.3289E-04

L = 1   I =   3  TAURH =  8.0858E-06  TAUSH =  2.2721E-06  TAU(I,L) =  1.0358E-05

      TRAINH - VECTOR

              1              2              3
        1.210000E+02 1.220000E+02 1.230000E+02

      TAUV - VECTOR

              1              2              3
        7.789517E-04   9.328912E-04   1.035787E-05

      VH1 - VECTOR

              1              2              3
        1.210000E+02 1.220000E+02 1.230000E+02
```

```
VH2 - VECTOR

        1              2              3
  7.789517E-04   9.328912E-04   1.035787E-05


TRAINH - OVERLAYED VECTOR

        1              2              3
  1.210000E+02   1.220000E+02   1.230000E+02


TAUV - OVERLAYED VECTOR

        1              2              3
  7.789517E-04   9.328912E-04   1.035787E-05
```

6.5. SUBSURFACE TRANSPORT

Output from Subroutine GRDWTR is found in file EXOUT:

```
INPUT PARAMETERS
================

V=          3.6000   D=        60.0000          R=  1.0000
DZERO=      0.0000   DONE=      0.0000
DBND=       0.0000   ALPHA=     0.0120

PULSE       CA =
NUMBER      N(9)

  1         1.01E+09
  2         2.64E+08
  3         1.52E+08
  4         5.52E+07
  5         2.00E+07
  6         7.28E+06

COMPOSITE GROUNDWATER OUTPUT

DISTANCE (X) = 12 METERS

 TIME        NUMBER        CONCENTRATION
 (DAY)        (N12)           (NO./L)

   1         0.00E+00        0.00E+00
   2         0.00E+00        0.00E+00
   3         0.00E+00        0.00E+00
   4         2.16E-27        7.21E-35
   5         1.80E-13        6.01E-21
   6         2.84E-06        9.45E-14
   7         5.01E+04        1.67E-03
   8         3.16E+01        1.05E-06
   9         8.38E+04        2.79E-03
  10         4.47E+04        1.49E-03
  11         3.45E+05        1.15E-02
  12         1.38E+06        4.59E-02
  13         3.40E+06        1.13E-01
  14         5.70E+06        1.90E-01
  15         7.23E+06        2.41E-01
  16         7.38E+06        2.46E-01
  17         6.49E+06        2.16E-01
  18         5.37E+06        1.79E-01
  19         4.54E+06        1.51E-01
  20         4.05E+06        1.35E-01
```

7. REFERENCES

American Society of Civil Engineers. 1977. Sedimentation Engineering. ASCE Manual No. 54. New York.

Bradford, J. 1987. Transport of MS-2 virus through saturated soil columns. M.S. Thesis, University of Arizona, Tucson, AZ.

Brady, N.C. 1974. The Nature and Properties of Soils. Macmillan Publishing Co., Inc., New York. p. 266-276.

Brandon, J.R. 1978. Parasites in soil/sludge systems. Sandia Laboratories Report SAND77-1970, Albuquerque, NM.

Brandon, J.R. and K.S. Neuhauser. 1978. Moisture effects on inactivation and growth of bacteria and fungi in sludges. Sandia Laboratories Report SAND78-1304, Albuquerque, NM.

Brownlie, L.E. 1976. Physiology, pathogenicity, ecology and epidemiology of Salmonella. In: Food-borne Microorganisms of Public Health Significance, Specialist Course for the Food Industry, Vol. I, K.A. Buckle et al., Ed. School of Food Technology, University of New South Wales, Kensington, New South Wales, Australia.

Burge, W.D. and N.K. Enkiri. 1978. Virus adsorption by five soils. J. Environ. Qual. 7: 73-76.

Camann, D.E., C.A. Sorber, B.P. Sagik, J.P. Glennon and D.E. Johnson. 1978. A model for predicting pathogen concentrations in wastewater aerosols. In: Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, B.P. Sagik and C.A. Sorber, Ed. Center for Applied Research and Technology, University of Texas at San Antonio. p. 240-271.

Chow, V.T., D.R. Maidment and L.W. Mays. 1988. Applied Hydrology. McGraw-Hill, New York.

Clark, S.S., R. Rylander and L. Larsson. 1983. Levels of gram-negative bacteria, Aspergillus fumigatus, dust, and endotoxin at compost plants. Appl. Environ. Microbiol. 45: 1501-1505.

Cram, E.B. 1924. The influence of low temperatures and of disinfectants on the eggs of Ascaris lumbricoides. J. Agric. Res. 27: 167-175.

Cram, E.B. 1943. The effect of various treatment processes on the survival of helminth ova and protozoan cysts in sewage. Sew. Works 15: 1119-1138.

Crane, S.R. and J.A. Moore. 1986. Modeling enteric bacterial die-off: A review. Water Air Soil Pollut. 27: 411-439.

Dimmick, R.L. and A.B. Akers. 1969. An Introduction to Experimental Aerobiology. John Wiley and Sons, Inc., New York.

Donahue, R.L., R.W. Miller and I.C. Shickluna. 1983. Soils, 5th Ed. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Drewey, W.A. and R. Eliassen. 1968. Virus movement in groundwater. J. Water Pollut. Contr. Fed. 40: 257-271.

Duboise, S.M., B.E. Moore and B.P. Sagik. 1976. Poliovirus survival and movement in a sandy forest soil. Appl. Microbiol. 31: 536-543.

Fields, M.L. 1979. Fundamentals of Food Microbiology. The Avi Publishing Company, Westport, CT. p. 107-109.

Gerba, C.P., C. Wallis and J.L. Melnick. 1975. Fate of wastewater bacteria and viruses in soil. Proc. ASCE, J. Irrig. Drain. Div. 101: 157-174.

Gifford, F.A. and S.R. Hanna. 1973. Modelling urban air pollution. Atmos. Environ. 7: 131-136.

Gillette, D.A. 1981. Production of dust that may be carried great distances. In: Desert Dust: Origin, Characteristics, and Effect on Man, T.Pewe, Ed. Geological Society of America Special Paper 186, p. 11-26.

Gregory, P.H. 1973. The Microbiology of the Atmosphere. Halsted Press, New York. p. 170-174.

Grondin, J. and C.P. Gerba. 1986. Virus dispersion in a coarse porous medium. Hydrol. Water Resour. Ariz. Southwest. 16: 11-15.

Gunderson, M.F. and K.D. Rose. 1948. Survival of bacteria in precooked fresh-frozen foods. Food Res. 13: 254-263.

Guthrie, R.K. 1972. Food Sanitation. The Avi Publishing Company, Westport, CT. p. 61-88.

Haridas, A. 1983. A mathematical model of microbial transport in porous media. Thesis, University of Delaware, Newark, DE.

Hersom, A.C. and E.D. Hulland. 1964. Canned Foods -- An Introduction to Their Microbiology. Chemical Publishing Co., New York.

Jay, J.M. 1978. Modern Food Microbiology. Van Nostrand, New York.

Keswick, B.H., D. Wang and C.P. Gerba. 1982. The use of microorganisms as ground water tracers: A review. Ground Water 20: 142-149.

Kibbey, H.J., C. Hagedorn and E.L. McCoy. 1978. Use of fecal streptococci as indicators of pollution in soil. Appl. Environ. Microbiol. 35: 711-717.

Lighthart, B. and A.S. Frisch. 1976. Estimation of viable airborne microbes downwind from a point source. Appl. Environ. Microbiol. 31: 700-704.

Marshall, K.C. 1971. Sorptive interactions between soil particles and microorganisms. pp 409-445. In: Soil Biochemistry, A.D. McLaren and J. Skujins, Ed. Marcel Dekker, New York.

Matson,E.A., S.G.Hornor and J.D.Buck. 1978. Pollution indicators and other microorganisms in river sediment. J. Water Pollut. Control Fed. 50: 13-19.

Matthess, G., A. Pekdeger and J. Schroefer. 1988. Persistence and transport of bacteria and viruses in groundwater -- a conceptual evaluation. J. Cont. Hyd. 2: 171-188.

Morris, M.E., J.S. Sivinski, J.R. Brandon, K.S. Neuhauser and R.L. Ward. 1979. A summary of recent developments in the sludge irradiation program at Sandia Laboratories. Sandia Laboratories Report SAND79-0629, Albuquerque, NM.

Naylor L.M. and R.C. Loehr. 1982. Priority pollutants in municipal sewage sludge. Biocycle. August. p. 18-22.

NOAA (National Oceanic and Atmospheric Administration). 1981. Local Climatological Data: Annual Summaries for 1981. Environmental Data and Information Service, National Climate Center, Asheville, N.C.

Pasquill, F. 1974. Atmospheric Diffusion: The Dispersion of Windborne Material from Industrial and Other Sources, 2d ed. Halsted Press, New York. 429 p.

Ray, B., O.W. Janssen and F.F. Busta. 1972. Characterization of the repair of injury induced by freezing Salmonella anatum. Appl. Microbiol. 23: 803-809.

Reddy, K.R., R. Khaleel and M.R. Overcash. 1981. Behavior and transport of microbial pathogens and indicator organisms in soils treated with organic wastes. J. Environ. Qual. 10: 255-266.

Simons, Li and Associates. 1982. Engineering Analysis of Fluvial Systems, SLA, Fort Collins, CO.

Soil Conservation Service. 1972. National Engineering Handbook, Section 4, Hydrology. U.S. Department of Agriculture, Washington, D.C.

Sorber, C.A., B.E. Moore, D.E. Johnson, H.J. Harding and R.E. Thomas. 1984. Microbiological aerosols from the application of liquid sludge to land. J. Water Pollut. Contr. Fed. 56: 830-836.

Sorber, C.A. and B.E. Moore. 1987. Survival and Transport of Pathogens in Sludge-amended Soil. Water Engineering Research Laboratory, U.S. EPA, Cincinnati, OH.

Stern, G. 1974. Pasteurization of liquid digested sludges. In: Proceedings of the National Conference on Municipal Sludge Management, Pittsburgh, PA. June. p. 163-169.

Sullivan, R., J.R. Tierney, E.P. Larkin, R.B. Read, Jr. and J.T. Peeler. 1971. Thermal resistance of certain oncogenic viruses suspended in milk and milk products. Appl. Microbiol. 22: 315-320.

Turner, D.B. 1969. Workbook of Atmospheric Dispersion Estimates. U.S. Public Health Service, Cincinnati, OH. p. 1-15, 41.

U.S. EPA. 1983a. Section 11.2, Fugitive Dust Sources. An AP-42 Update of Open Source Fugitive Dust Emissions. Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA 450/4-83-010.

U.S. EPA. 1983b. Process Design Manual for Land Application of Municipal Sludge. Municipal Environmental Research Laboratory, Cincinnati, OH. EPA 625/1-83-016.

U.S. EPA. 1985. Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites. Prepared by Midwest Research Institute for the Office of Health and Environmental Assessment, Washington, D.C. EPA/600/8-85/002. NTIS PB85-192219.

U.S. EPA. 1988. Occurrence of Pathogens in Distribution and Marketing Municipal Sludges. Prepared by County Sanitation Districts of Los Angeles County for the Health Effects Research Laboratory, Office of Research and Development, Research Triangle Park, NC. EPA/600/1-87/014. NTIS PB88 154273.

U.S. EPA. 1989a. Development of Risk Assessment Methodology for Land Application and Distribution and Marketing of Municipal Sludge. Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH. EPA/600/6-89/001.

U.S. EPA. 1989b. Standards for the Disposal of Sewage Sludge: Proposed Rule. Federal Register 54(23): 5886-5887.

U.S. FDA (U.S. Food and Drug Administration). 1978. FY78 Total Diet Studies.

van Genuchten, M.T. 1978. Mass transport in saturated-unsaturated media: One dimensional solutions. Report to the US Salinity Laboratory, USDA, Riverside, CA. Report No. 78-WR-11.

van Genuchten, M.T. 1986. A numerical model for water and solute movement in and below the root zone; model description and user manual. USSL research report, US Salinity Laboratory, USDA, Riverside CA. Draft report.

van Genuchten, M.T. and W.J. Alves. 1982. Analytical solutions on the one-dimensional convective-dispersive solute transport equation. USDA Technical Bulletin No. 1661.

Veerannan, K.M. 1977. Some experimental evidence on the viability of Ascaris lumbricoides ova. Current Sci. 46: 386-387.

Ward, R.L., C.S. Ashley and R.H. Moseley. 1976. Heat inactivation of poliovirus in wastewater sludge. Appl. Environ. Microbiol. 32: 339-346.

Ward, R.L. and C.S. Ashley. 1977. Inactivation of enteric viruses in wastewater sludge through dewatering by evaporation. Appl. Environ. Microbiol. 34: 564-570.

Weiser, H.H., G.J. Mountney and W.A. Gould. 1971. Practical Food Microbiology and Technology. The Avi Publishing Company, Westport, CT.

Whittaker, R.H. 1975. Communities and Ecosystems, 2nd Ed. Macmillan Publishing Co., Inc., New York. 387 p.

Wiley, B.B. and S.C. Westerberg. 1969. Survival of human pathogens in composted sewage. Appl. Microbiol. 18: 994-1001.

Williams, J.R. 1975. Sediment-yield prediction with universal equation using runoff energy factor, in present and prospective technology for predicting sediment yields and sources, ARS-40. U.S. Department of Agriculture--Agricultural Research Service. p. 244-252.

Yanco, W.A. 1988. Occurrence of Pathogens in Distribution and Marketing Municipal Sludges. Health Effects Research Laboratory, U.S. EPA, Research Triangle Park, NC.

Yeager, J.G. and R.T. O'Brien. 1979. Enterovirus inactivation in soil. Appl. Environ. Microbiol. 38: 694-702.

Younger, J.S. 1956. Thermal inactivation studies with different strains of poliovirus. J. Immun. 78: 282-290.

APPENDIX A. VARIABLES AND DEFAULT VALUES

TABLE A-1

Position Number, Name, Default Values, and Definition of Input Variables

Position	Name	Default Value I	Default Value II	Default Value III	Default Value IV	Default Value V	Definition
1	ASCRS	#	#	#	#	#	Pathogen density (Pathogens/kg)
2	APRATE	1×10^4	1.25×10^4	1.25×10^4	2.5×10^4	2.5×10^4	Application rate (kg/ha)
3	ASCIN	0	0	0	0	0	Pathogen concentration (Pathogens/ha)
4	TREG	**	**	**	**	**	Waiting period (months) required by U.S. EPA Pathogen Reduction Regulations
5	UPLIM	1×10^9	1×10^9	1×10^9	1×10^9	1×10^9	Upper limit for pathogen concentration
6	APMETH	+1	-1	-1	+1	+1	Application method
7	AREA	10	10	10	0.015	0.05	Area of field or garden (ha)
8	TEMP	--	--	--	--	--	Air temperature (°C)
9	AQUIFR	10	10	10	10	10	Aquifer thickness (m)
10	POROS	0.3	0.3	0.3	0.3	0.3	Aquifer porosity
11	FILTR8	2	2	2	2	2	Infiltration rate (cm/hr)
12	MID	*	*	*	*	*	Minimum infective dose (number of pathogens)
13	TRAIN	-2	-2	-2	-2	-2	Time of rainfall (hr)
14	RDEPTH	5	5	5	5	5	Rainfall depth (cm)
15	TK	--	--	--	--	--	Time since last rain began
16	TIRRG	--	--	--	--	--	Time since last irrigation began
17	IRMETH	0	0	0	0	0	Irrigation method
18	DILIRR	0	1	1	0	0	Fraction of irrigation water that is contaminated
19	NIRRIG	2	2	2	2	2	Number of irrigations per week
20	IRRATE	0.5	0.5	0.5	0.5	0.5	Irrigation rate: (cm/hr)
21	DEPTH	2.5	2.5	2.5	2.5	2.5	Depth of irrigation water (cm)
22	COUNT	0	0	0			Pathogen concentration in irrigation sludge (pathogens/kg)
23	TWIND	60	60	60	60	60	Time of windstorm (hr)
24	DWIND	6	6	6	6	6	Duration of windstorm (hrs)
25	WINDSP	18	18	18	18	18	Wind speed during windstorm (m/sec)
26	EPSMLT	0.33	0.33	0.33	0.33	0.33	Particle size multiplier for tilling emissions
27	ESILT	0.4	0.4	0.4	0.4	0.4	Fractional silt content of soil
28	EHT	2	2	2	2	2	Height of box model (m)
29	SCRIT	7.5	7.5	7.5	7.5	7.5	Critical windspeed (m/sec)

TABLE A-1 (Continued)

Position Number, Name, Default Values, and Definition of Input Variables

Position	Name	Default Value I	II	III	IV	V	Definition
30	COVER	0	0.9	0.9	0	0.9	Percent of ground surface covered by vegetation
31	AEREFF	0.001	0.001	0.001	0.001	0.001	Efficiency of aerosol formation
32	BREEZE	4	4	4	4	4	Normal wind speed (m/sec)
33	HT	1.6	1.6	1.6	1.6	1.6	Height of receptor downwind (m)
34	ANDAY	--	--	--	--	--	Day in annual temperature cycle, set by user
35	TMAX	#	#	#	#	#	Maximum monthly average temperature (calculated)
36	TMIN	#	#	#	#	#	Minimum monthly average temperature (calculated)
37	SLOPES*	*	*	*	*	*	Slope of inactivation vs temperature curve, moist soil
38	NTRCPS*	*	*	*	*	*	Intercept of inactivation vs temperature curve, moist soil
39	SLOPEP*	*	*	*	*	*	Slope of inactivation vs temperature curve, dry soil
40	NTRCPP*	*	*	*	*	*	Intercept of inactivation vs temperature curve, dry soil
41	ASLSUR	0.9	0.9	0.9	0.9	0.9	Transfer fraction: Application to soil surface
42	FSSUR	1	1	1			Transfer fraction: Application to subsurface soil
43	FRRAIN	--	--	--	--	--	Transfer fraction: Soil surface to surface runoff
44	SUBSOL*	*	*	*	*	*	Transfer fraction: Soil surface to subsurface soil
45	SUSPND*	*	*	*	*	*	Transfer fraction: Soil surface to soil surface water
46	FCROP1	1×10^{-8}			1×10^{-8}		Transfer fraction: Soil surface to crop 1
47	FCROP2	0.006			0.006		Transfer fraction: Soil surface to crop 0
48	FCROP3	1×10^{-3}			1×10^{-3}		Transfer fraction: Soil surface to crop -1
49	FCROP4	1×10^{-4}			1×10^{-4}		Transfer fraction: Crop 1 to soil surface
50	FCROP5	0.012			0.012		Transfer fraction: Crop 0 to soil surface
51	FCROP6	0			0		Transfer fraction: Crop -1 to soil surface
52	FCROP7	2×10^{-4}			2×10^{-4}		Transfer fraction: Subsurface soil to crop -1
53	FRGRND*	*	*	*			Transfer fraction: Subsurface soil to groundwater
54	SSWTCS*		*	*		*	Transfer fraction: Soil surface water to crop surface
55	PSTMG					0.5	Transfer fraction: Grass removed during mowing
56	CSTSS		0.01	0.01		0.01	Transfer fraction: Crop surface to soil surface
57	SSTCS		1×10^{-5}	1×10^{-5}			Transfer fraction: Soil surface to crop surface
58	CSTSSW	0.75	0.5	0.5	0.75	0.5	Transfer fraction: Crop surface to soil surface water
59	DTCTMT		0	0			Transfer fraction: Animal consumption to meat

TABLE A-1 (Continued)

Position Number, Name, Default Values, and Definition of Input Variables

Position	Name	Default Value I	II	III	IV	V	Definition
60	DTCTMK		0	0			Transfer fraction: Animal consumption to milk
61	TMTSS		0.7				Transfer fraction: Manure to soil surface
62	TMTH		0.001	0.001			Transfer fraction: Manure to hide
63	TMTU		0.001	0.001			Transfer fraction: Manure to udder
64	HTM		0.1	0.1			Transfer fraction: Hide to meat
65	UTM		0.05	0.05			Transfer fraction: Udder to milk
66	CROP	1					Type of crop
67	TCULT	-2			-2		Cultivation time (hr)
68	TCROP	720	0	0	720	240	Time crop surface is present (hr)
69	THARV	1800		720	1680		Harvest time (hrs)
70	YIELD1	2.5×10^7			2.5×10^7		Yield of tomatoes (g/ha)
71	YIELD2	2.5×10^7			2.5×10^7		Yield of zucchini (g/ha)
72	YIELD3	1×10^6			1×10^6		Yield of carrots (g/ha)
73	HAY		1.6	1.6			Grass present in field, or hay yield (kg/m^2)
74	PLNT1				0.4		Fraction of home garden in above-ground crop
75	PLNT2				0.3		Fraction of home garden in on-ground crop
76	PLNT3				0.3		Fraction of home garden in below-ground crop
77	PPG	--			--		Pathogen concentration on crop (paqthogens/g)
78	CATTLE		1	1			Type of cattle
79	COWS		12	12			Herd size
80	STORAG			720			Length of forage storage (days)
81	FORAG		7	7			Forage consumed per cow per day (kg)
82	ALFALF			30			Percent of feed which is harvested crop
83	SCNSMP		1.1	1.1			Soil consumed per cow per day (kg)
84	FATTEN			720			Number of hours cattle to be fed forage
85	TSLOTR		-2	-2			Time of slaughter (day)

#No default values, must be supplied by user
*Pathogen-specific, see Table A-2
**Practice- and crop-specific
--Calculated internally by the program

TABLE A-2

Pathogen-Specific Default Values

Position	Name	Pathogen	Default Value I	II	III	IV	V	Definition
12	MID	Salmonella	10	10	10	10	10	Minimum Infective Dose (Number of pathogens ingested)
		Ascaris	1	1	1	1	1	
		Enterovirus	1	1	1	1	1	
37	SLOPES	Salmonella	0.0206	0.0206	0.0206	0.0206	0.0206	Process function parameter used to calculate die-off of pathogens in soil as a function of temperature
		Ascaris						
		Enterovirus	0.00145	0.00145	0.00145	0.00145	0.00145	
38	NTRCPS	Salmonella	2.113	2.113	2.113	2.113	2.113	Process function parameter used to calculate die-off of pathogens in soil as a function of temperature
		Ascaris						
		Enterovirus	2.957	2.957	2.957	2.957	2.957	
39	SLOPEP	Salmonella	0.00449	0.00449	0.00449	0.00449	0.00449	Process function parameter used to calculate die-off of pathogens in particulates as a function of temperature
		Ascaris						
		Enterovirus						
40	NTRCPP	Salmonella	1.435	1.435	1.435	1.435	1.435	Process function parameter used to calculate die-off of pathogens in particulates as a function of temperature
		Ascaris						
		Enterovirus						
44	SUBSOL	Salmonella	$5x10^{-4}$	$5x10^{-4}$	$5x10^{-4}$	$5x10^{-4}$	$5x10^{-4}$	Transfer fraction: Soil surface to subsurface soil
		Ascaris	0	0	0	0	0	
		Enterovirus	0.001	0.001	0.001	0.001	0.001	
45	SUSPND	Salmonella	0.005	0.001	0.001	0.005	0.001	Transfer fraction: Soil surface to soil surface water
		Ascaris	0.01	0	0	0.01	0	
		Enterovirus	0.01	0.001	0.001	0.01	0.001	

TABLE A-2 (Continued)

Pathogen-Specific Default Values

Position	Name	Pathogen	Default Value I	II	III	IV	V	Definition
53	FRGRND	Salmonella	0.001	0.001	0.001			Transfer fraction: Subsurface soil to groundwater
		Ascaris	0	0	0			
		Enterovirus	0.001	0.001	0.001			
54	SSWTCS	Salmonella		0.1	0.1		0.1	Transfer fraction: Soil surface water to crop surface
		Ascaris		0.05	0.05		0.05	
		Enterovirus		0.1	0.1		0.1	

TABLE A-3

Proposed Initial Value Menu for Pathogen Concentration Parameter, ASCRS

	Estimated Mean Organisms/kg (dry wt) of Material*		
Material	Salmonella	Ascaris	Viruses
Raw Liquid Municipal Sludge	5×10^5	5×10^3	5×10^5
Liquid Digested Sludge (Anaerobic)	5×10^4	5×10^3	1×10^5
Liquid Digested Sludge (Aerobic)	5×10^4	5×10^3	1×10^5
Dried Digested Sludge	1×10^3	5×10^2	1×10^4
Composted Sludge	1×10^6**	1×10^0	5×10^1
Sludge Amended Soil	2×10^3	1×10^0	3×10^3

*Adapted from Sorber and Moore, 1987

**Assumes regrowth as described by Yanco, 1988

TABLE A-4

Variables and Default Values for Subroutine RISK

Position	Name	Default Value	Definition
2	COOKA	1.E-5	Survival of Ascaris during cooking
3	COOKP	1.E-5	Survival of enterovirus during cooking
4	COOKS	1.E-30	Survival of Salmonella during cooking
5	DRECTC	0.1	Ingestion rate of crop surface from direct contact in g/day
6	DRECTS	0.1	Ingestion rate soil from direct contact in g soil/day
7	IBLAN	0	Flag for blanching of vegetables
8	ICAN	0	Flags canning sequence. If ICAN=1, the vegetable-exposure risk calculation will include the effects of storage of raw vegetable, washing, blanching, canning, storage of cans and cooking.
9	ICANG	0	Flag for vegetable canning alone
10	ICOOK	0	Flag for cooking of vegetables and meat
11	IFREE	0	Flags freezing sequence. If IFREE=1, the vegetable-exposure risk calculation will include the effects of storage of raw vegetable, washing, blanching freezing, frozen storage and cooking.
12	IFREG	0	Flag for vegetable freezing alone
13	IPAST	0	Flag for pasteurization of milk
14	ISTRH	1	Flag for storage of vegetables before processing. When ISTRH=1, the effects of storage on pathogen population are included in the vegetable-exposure risk calculation. When ISTRH=0, these effects are not included.

TABLE A-4 (Continued)

Variables and Default Values for Subroutine RISK

Position	Name	Default Value	Definition
15	ISTRP	0	Flag for storage of processed vegetables
16	IWASH	1	Flag for washing of vegetables
17	PASTB	1.E-9	Survival of Salmonella after pasteurization
18	PASTA	0.001	Survival of Ascaris after pasteurization
19	PASTP	0.001	Survival of enterovirus after pasteurization
20	TEMI2	4	Temperature (°C) of milk storage before pasteurization
21	TEMI4	4	Temperature (°C) of milk storage after pasteurization
22	TEMP2	7	Temperature (°C) of storage of vegetables before processing
23	TEMP4	0	Temperature (°C) of storage of frozen meat
24	TMIS2	24	Time (hours) of milk storage before pasteurization
25	TMIS4	24	Time (hours) of milk storage after pasteurization
26	TMP2M	4	Temperature (°C) of storage of meat after slaughter
27	TMP7F	-4	Temperature (°C) of storage of frozen foods
28	TMP7N	20	Temperature (°C) of storage of canned foods
29	TSTM2	720	Duration in hours of meat storage (unfrozen between slaughter and freezing)
30	TSTR2	168	Duration (hours) of vegetable storage before processing

TABLE A-4 (Continued)

Variables and Default Values for Subroutine RISK

Position	Name	Default Value	Definition
31	TSTR4	120	Time of storage of frozen meat
32	TSTR7	720	Duration of vegetable storage after processing
33	VOLPND	1.E2	Volume (m^3) of runoff pond
34	XDIST	200	Distance (in meters) downwind between particulate source and exposed individual
35	YDIST	0	Lateral distance (in meters) of human receptor from a line directly downwind of aerosol source

TABLE A-5

Variables and Default Values for Subroutine RAINS

Position	Name	Default Value	Function
2	PDUR	2	Duration of rainfall (hours)
3	PTOT	5.0	Total rainfall (cm)
4	BTLAG	0.5	Basin time lag (hr)
5	CN	80	Curve number
6	AMC	2	Antecedent moisture conditions
7	STAD	0.4	Storm advancement coefficient
8	USLEK	0.4	USLE K value (soil erodibility factor)
9	USLEL	3.0	USLE L value (slope length factor)
10	USLES	0.25	USLE S value (slope steepness factor)
11	USLEC	0.5	USLE C value (cover management factor)
12	USLEP	1.0	USLE P value (supporting practices)
13	PI	SUSPND	Pathogen suspension factor
14	WSOIL	1.33	Bulk density of soil (g/cm^3)

TABLE A-6

Variables and Default Values for Subroutine GRDWTR

Position	Name	Default Value	Function
	CA	FRGRND*N(8)	Initial number of organisms
2	V	3.6	Velocity of groundwater (cm/hr)
3	D	60	Dispersion coefficient (cm^2/hr)
4	R	1.0	Retardation coefficient
5	DZERO	0	Exponential growth rate
6	DONE	0	Exponential inactivation rate
7	DBND	0	Decaying input concentration
8	ALPHA	0.012	Exponential decay of input (per hr)
9	XI	50	Starting distance (m) from source
10	DX	50	Distance increment (m) in calculation
11	XM	50	Maximum distance (m) from source
12	DT	1	Time increment (hr) in calculation

TABLE A-7

Transfer Factors and Functions for Practices I - V

	PRACTICE				
Transfer	I	II	III	IV	V
TR01	ASCIN	ASCIN	ASCIN	ASCIN	ASCIN
TR12	N(1)	---	---	N(1)	N(1)
TR13	Eq. 3-1[1]	Eq. 3-1	Eq. 3-1	0.003•ASCRS	0.003•ASCRS
TR14	---	ASLSUR•N(1)	ASLSUR•N(1)	---	---
TR18	FSSUR•N(1)	FSSUR•N(1)	FSSUR•N(1)	---	---
TR114	---	(1-ASLSUR)•N(1)	(1-ASLSUR)•N(1)	---	---
TR23	ASCIN•(Eq. 3-2)	---	---	0.0015•ASCRS	0.0015•ASCRS
TR24	N(2)	---	---	N(2)	N(2)
TR43	N(4)•(Eq. 3-2)	---	---	N(4)•(Eq. 3-2)	---
TR45	Eq. 3-3	Eq. 3-3	Eq. 3-3	Eq. 3-3	Eq. 3-3
TR46	FRRAIN•N(4)	FRRAIN•N(4)	FRRAIN•N(4)	---	---
TR47	Eq. 3-4	Eq. 3-4	Eq. 3-4	Eq. 3-4	Eq. 3-4
TR48	SUBSOL•N(4)	SUBSOL•N(4)	SUBSOL•N(4)	SUBSOL•N(4)	SUBSOL•N(4)
TR411	SUSPND•N(4)	SUSPND•N(4)	SUSPND•N(4)	SUSPND•N(4)	SUSPND•N(4)
TR414	FCROPn•N(4)	SSTCS•N(4)/24	SSTCS•N(4)/24	Eq. 3-9	SSTCS•N(4)/24
TR417	---	SCNSMP•COWS•N(4)/2•10^6	---	---	---
TR617	---	(0.02•COWS•N(6))/VOLPND	---	---	---
TR89	FRGRND•N(8)	FRGRND•N(8)	FRGRND•N(8)	---	---
TR814	FCROP7•N(8)	---	---	FCROP7•PLNT3•N(8)	---
TR910	N(9)	N(9)	N(9)	---	---
TR912	FLUX(IMAX)	FLUX(IMAX)	FLUX(IMAX)	---	---

---

[1] Equations listed at end of table.

TABLE A-7 (Continued)

Transfer Factors and Functions for Practices I - V

Transfer	PRACTICE				
	I	II	III	IV	V
TR1011[2]	(1-AEREFF)•SOURCE or 0.9•(1-AEREFF)•SOURCE	(1-AEREFF)•SOURCE or 0.9•(1-AEREFF)•SOURCE	(1-AEREFF)•SOURCE or 0.9•(1-AEREFF)•SOURCE	--- ---	--- ---
TR1013	AEREFF•SOURCE	AEREFF•SOURCE	AEREFF•SOURCE	---	---
TR1014	0.1•(1-AEREFF)•SOURCE	0.1•(1-AEREFF)•SOURCE	0.1•(1-AEREFF)•SOURCE	---	---
TR1104	N(11)-TR1114	N(11)-TR1114	N(11)-TR1114	N(11)-TR1114	N(11)-TR1114
TR1114	FCROPn•N(11)	SSWTCS•N(11)	SSWTCS•N(11)	Eq. 3-10	SSWTCS•N(11)
TR144	0.0016667•N(14)	CSTSS/24.•N(14)	CSTSS/24.•N(14)	Eq. 3-11	CSTSS/24.•N(14)
TR147	Eq. 3-5	Eq. 3-5	Eq. 3-5	Eq. 3-5	Eq. 3-5a
TR1411	CSTSSW•N(14)	CSTSSW•N(14)	CSTSSW•N(14)	Eq. 3-12	CSTSSW•N(14)
TR1415	N(14)	---	N(14)	N(14)	---
TR1417	---	Eq. 3-6	---	---	---
TR1516	N(15)	---	---	N(15)	---
TR1517	---	---	Eq. 3-8	---	---
TR1718	---	DTCTMT•N(17)	DTCTMT•N(17)	---	---
TR1719	---	4x10^{12}•COWS	4x10^{12}•COWS	---	---
TR1720	---	DTCTMK•N(17)	DTCTMK•N(17)	---	---
TR194	---	TMTSS•N(19)	---	---	---
TR1914	---	Eq. 3-7	---	---	---
TR1921	---	TMTH•N(19)	TMTH•N(19)	---	---
TR1922	---	TMTU•N(19)	TMTU•N(19)	---	---
TR2118	---	HTM•N(21)	HTM•N(21)	---	---
TR2220	---	UTM•N(22)	UTM•N(22)	---	---

---

[2] Conditional depending on presence of a crop.

TABLE A-7 (Continued)

Transfer Factors and Functions for Practices I - V

Eq. 3-1	TR13	= AEREFF•5000•IRRATE•ASCIN/APRATE
Eq. 3-2	TR	= 6.04•EPSMLT•(ESILT••0.6)/2X10^6
Eq. 3-3	TR45	= 0.069•(1-COVER)•((WINDSP/SCRIT)••3)•N(4)/2x10^5
Eq. 3-4	TR47	= DRECTS•0.001•N(4)/(2.0x10^6•24)
Eq. 3-5	TR1407	= DRECTC•0.001•N(14)/(1.6x10^4•24)
Eq. 3-5a	TR1407	= DRECTC•PSTMG•N(14)/(1.6x10^4•26)
Eq. 3-6	TR1417	= (FORAG•COWS)•N(14)/(1.6x10^4)
Eq. 3-7	TR1914	= (1-(TMTSS+TMTH+TMTU))•N(19)
Eq. 3-8	TR1517	= FORAG•COWS•ALFALF•N(15)/(HAY•(1x10^4))
Eq. 3-9	TR414	= N(4)•((FCROP1•PLNT1)+(FCROP2•PLNT2)+(FCROP3•PLNT3))
Eq. 3-10	TR1114	= N(11)•(FCROP4•PLNT1 + FCROP5•PLNT2)
Eq. 3-11	TR144	= 0.0016667•N(14)•(1-PLNT3)
Eq. 3-12	TR1411	= CSTSS•N(14)•(1-PLNT3)

TABLE A-8

Transfer Times for Practices I - V

Transfer	PRACTICE I	 II	 III	 IV	 V
TR01	0	0	0	0	0
TR12	24	--	--	AREA/0.01	AREA/0.01
TR13	≤DEPTH/IRRATE (spray application)	≤DEPTH/IRRATE (spray application)	≤DEPTH/IRRATE (spray application)	Up to AREA/0.01	Up to AREA/0.01
TR14	--	15	15	--	--
TR18	10 (injection application)	10 (injection application)	10 (injection application)	10 (injection application)	10 (injection application)
TR114	--	15	15	--	--
TR23	24 to 24+(AREA/5)	--	--	Hourly, up to AREA/0.01+AREA/0.005 (IV and V)	
TR24	24 + AREA/5	--	--	AREA/0.01+AREA/0.005	AREA/0.01+AREA/0.005
TR43	TCULT to TCULT+(AREA/5) or biweekly, 336 hr to THARV for AREA/5 hr	--	--	TCULT to TCULT+(AREA/0.005) or biweekly, 336 hr to THARV for AREA/0.005 hr	-- --
TR45	TWIND to TWIND+DWIND	TWIND to TWIND+DWIND	TWIND to TWIND+DWIND	TWIND to TWIND+DWIND	TWIND to TWIND+DWIND
TR46	TRAIN	TRAIN	TRAIN	--	--
TR47	Hourly	Hourly	Hourly	Hourly	Hourly
TR48	Hourly during infiltration	Hourly during infiltration	Hourly during infiltration	Hourly during infiltration	Hourly during infiltration
TR411	TRAIN, or TIRRG=0	TRAIN, or TIRRG=0	TRAIN, or TIRRG=0	TRAIN, or TIRRG=0	TRAIN, or TIRRG=0
TR414	TWIND (aboveground) and THARV-1 (all)	Hourly	Hourly	TWIND (aboveground) and THARV-1 (all)	Hourly after TCROP
TR415	--	--	--	--	--
TR417	--	Daily*	--	--	--
TR617	--	Daily*	--	--	--
TR89	Hourly during infiltration	Hourly during infiltration	Hourly during infiltration	--	--
TR814	THARV-1 (below-ground)	--	--	THARV-1 (below-ground)	--

TABLE A-8 (Continued)

Transfer Times for Practices I - V

Transfer	PRACTICE				
	I	II	III	IV	V
TR910	Hourly	Hourly	Hourly	--	--
TR912	Hourly after TR89	Hourly after TR89	Hourly after TR89	--	--
TR1011	Hourly during irrigation	Hourly during irrigation	Hourly during irrigation	--	--
TR1013	Hourly during irrigation	Hourly during irrigation	Hourly during irrigation	--	--
TR1014	Hourly during irrigation	Hourly during irrigation	Hourly during irrigation	--	--
TR1104	At end of each irrigation	At end of each irrigation	At end of each irrigation	At end of each irrigation	At end of each irrigation
TR1114	At end of each irrigation	At end of each irrigation	At end of each irrigation	At end of each irrigation	At end of each irrigation
TR144	Hourly for 5 days after wind	Hourly	Hourly	Hourly for 5 days after wind	Hourly
TR147	Daily after TCROP	Daily after 54 hours	Daily after 54 hours	Daily after TCROP	Daily after TCROP or weekly during mowing
TR1411	At start of each irrigation	At start of each irrigation	At start of each irrigation	At start of each irrigation	At start of each irrigation
TR1415	THARV	--	THARV	Hourly after THARV if TEMP > 0°C	--
TR1417	--	Daily*	--	--	--
TR1516	THARV + 24	--	--	Hourly after THARV + 5 if TEMP > 0°C	--
TR1517	--	--	Daily after THARV+STORAG		--
TR1718	--	Daily*	Daily after THARV+STORAG+48	--	--
TR1719	--	Daily*	Daily after THARV+STORAG+12	--	--
TR1720	--	Twice daily*	Twice daily after THARV+STORAG+48	--	--
TR1904	--	Daily*	--	--	--
TR1914	--	Daily*	--	--	--

TABLE A-8 (Continued)

Transfer Times for Practices I - V

	PRACTICE				
Transfer	I	II	III	IV	V
TR1921	--	Daily*	Daily after THARV+STORAG+14	--	--
TR1922	--	Daily*	Daily after THARV+STORAG+14	--	--
TR2118	--	TSLOTR	TSLOTR	--	--
TR2220	--	Twice daily*	Twice daily after THARV+STORAG+48	--	--

*Starting time depends on waiting period mandated by proposed U.S. EPA pathogen reduction requirements (U.S. EPA, 1989)

TABLE A-9

Average Monthly Temperatures (°F) at Several Reporting Stations, Continental United States

Location	Jan	Jan(°C)	Feb	Mar	Apr	May	June	July	Jul(°C)	Aug	Sept	Oct	Nov	Dec
Bakersfield, CA	47.4	8.5	52.7	57.0	62.6	70.0	77.6	83.9	28.8	81.7	75.9	66.7	55.9	48.2
Colorado Spgs, CO	28.8	-1.8	32.7	36.3	46.0	55.4	65.5	70.9	21.6	68.7	61.0	50.7	37.9	31.6
Tampa, FL	60.8	16.0	62.0	66.7	71.5	76.9	80.7	81.9	27.7	82.0	80.6	74.6	67.0	61.9
Augusta, GA	47.0	8.3	49.2	56.4	63.9	72.1	78.7	81.2	27.3	80.3	75.6	64.9	54.7	47.8
Moline, IL	21.3	-5.9	25.9	36.2	50.3	61.1	71.2	75.1	23.9	73.1	65.0	53.8	39.0	26.7
Jackson, MS	47.7	8.7	50.6	57.3	65.3	72.5	79.6	81.9	27.7	81.5	76.9	66.2	55.6	49.2
Charlotte, NC	41.6	5.3	43.7	51.0	60.0	68.8	75.9	78.7	25.9	77.5	72.2	61.4	50.9	43.1
Fargo, ND	4.9	-15.0	9.6	24.2	42.3	54.9	64.7	70.1	21.1	68.0	58.1	45.7	27.5	12.7
Syracuse, NY	23.9	-4.5	24.0	33.5	45.4	57.0	66.2	71.2	21.8	69.2	62.2	51.4	40.2	28.1
Dayton, OH	28.4	-2.0	30.8	40.1	51.4	61.7	71.1	75.0	23.9	73.2	66.6	55.3	42.4	32.1
Salem, OR	38.9	3.8	42.8	45.4	49.7	55.5	61.1	66.6	19.2	66.3	62.0	53.1	45.0	41.1
Abilene, TX	44.1	6.7	47.9	56.0	65.1	72.3	80.1	83.5	28.6	82.9	76.1	66.0	53.9	46.3

TABLE A-10

Constants for Temperature Dependence of Process Functions for Bacteria in Soil*

Organism	Condition	Slope (A)	Intercept (B)	R**
Salmonella				
	Moist soil	0.0206	2.113	0.91
	Dry partic.	0.00449	1.435	0.39
E. coli				
	Moist soil	0.0196	2.284	0.97
Strep. faecalis				
	Moist soil	0.0099	2.842	0.99
	Dry partic.	0.0201	2.717	0.99
Enterovirus				
	Moist soil	0.00145	2.957	0.99

* RHO = N_0*(10**(-(10**((A*TEMP)-B)))) for bacteria,
RHO = N_0*(10**(-(10**((A*TEMP**2)-B)))) for enteroviruses

** R = Correlation coefficient of data with fitted line

Data from Crane and Moore, 1986; Kibbey et al., 1978.

TABLE A-11

Optional Variables for Growth or Inactivation Rate

	Practice				
Compartment	I	II	III	IV	V
1	PROC1	PROC1	PROC1	---	---
2	PROC1	---	---	PROC1	PROC1
3	---	HCRIT	HCRIT	---	---
4	PROC1	PROC1	PROC1	PROC1	PROC1
5	PROC2	PROC2	PROC2	PROC2	PROC2
6	PROC3	PROC3	PROC3	---	---
7	---	---	---	---	---
8	PROC1	PROC1	PROC1	PROC1	PROC1
9	PROC3	PROC3	PROC3	---	---
10	PROC3	PROC3	PROC3	---	---
11	PROC3	PROC3	PROC3	PROC3	PROC3
12	PROC3	PROC3	PROC3	---	---
13	HCRIT	HCRIT	HCRIT	---	---
14	PROC1	PROC1	PROC1	PROC1	PROC1

Definitions:

PROC1 = Growth or inactivation rate for pathogens in soil

PROC2 = Growth or inactivation rate for pathogens in dry particulates

PROC3 = Growth or inactivation rate for pathogens in water

HCRIT = Inactivation rate for pathogens in water droplet aerosol

$\text{PROCn} = \log_{10}(N_{t+1}/N_t)$

$\text{HCRIT} = \log_{10}(N_{t+1}/N_t)$

where:

N is the number of organisms in the compartment

t is the time in hours (PROCn) or minutes (HCRIT)

TABLE A-12

Process Functions for Practices I - V

PROCESS	PATHOGEN Salmonella	 Ascaris		 Enterovirus
RHO1	RHO1 = (RHOA-1.0)•N(1)[1]	None RHO1 = -0.00041•N(1) RHO1 = -0.65•N(1)	(Temp < 20) (20 ≤ Temp < 40) (Temp ≥ 40)	RHO1 = (RHOB-1.0)•N(1)[2]
RHO2	RHO2 = (RHOA-1.0)•N(2)	None RHO2 = -0.00041•N(2) RHO2 = -0.65•N(2)	(Temp < 20) (20 ≤ Temp < 40) (Temp ≥ 40)	RHO2 = (RHOB-1.0)•N(2)
RHO3	None	None		None
RHO4	RHO4 = (RHOA-1.0)•N(4)	RHO4 = 0 RHO4 = -0.000533•N(4) RHO4 = -0.7845•N(4) RHO4 = -0.25083•N(4)	(Temp < 20 or TIRRG ≤ 8) (20 ≤ Temp < 40) (40 ≤ Temp ≤ 50) (TEMP > 50)	RHO4 = (RHOB-1.0)•N(4)
RHO5	RHO5 = (RHOA-1.0)•N(5)	RHO5 = 0		RHO5 = 0
RHO6	RHO6 = -0.0119926•N(6)	RHO6 = -0.000533•N(6)		RHO6 = -0.0119926•N(6)
RHO7	0	0		0
RHO8	RHO8 = (RHOA-1.0)•N(8)	RHO8 = -0.00053•N(8)		RHO8 = (RHOB-1.0)•N(8)
RHO9	RHO9 = -0.0119926•N(9)	RHO9 = -0.000533•N(9)		RHO9 = -0.0119926•N(9)
RHO10	0	0		0
RHO11	RHO11 = -0.0119926•N(11)	RHO11 = -0.000533•N(11)		RHO11 = -0.0119926•N(11)

TABLE A-12 (Continued)

Process Functions for Practices I - V

	PATHOGEN		
PROCESS	Salmonella	Ascaris	Enterovirus
RHO12	RHO12 = -0.0119926∗N(12)	RHO12 = -0.000533∗N(12)	RHO12 = -0.0119926∗N(12)
RHO13	Included in aerosol calculations as HCRIT	Included in aerosol calculations as HCRIT	Included in aerosol calculations as HCRIT
RHO14	RHO14 = (RHOA-1)∗N(14) (RHO14 = 0 for below-ground crops)	RHO14 = -0.7845∗N(14) (RHO14 = 0 for below-ground crops)	RHO14 = (RHOB-1.0)∗N(14) (RHO14 = 0 for below-ground crops)
RHO15	RHO15 = (RHOA-1)∗N(15) (RHO15 used only in Practice III)	RHO15 = -0.7845∗N(14) (RHO15 used only in Practice III)	RHO15 = (RHOB-1.0)∗N(15) (RHO15 used only in Practice III)
RHO16	0	0	0
RHO17	See text for explanation	None	None
RHO18	RHO18 = 0.076∗N(18)	None	None
RHO19	See text for explanation	None	None
RHO20	RHO20 = 0.076∗N(20)	None	None
RHO21	RHO21 = -1/24∗N(21)	RHO21 = -1/24∗N(21)	RHO21 = -1/24∗N(21)
RHO22	RHO22 = -1/24∗N(22)	RHO22 = -1/24∗N(22)	RHO22 = -1/24∗N(22)

---

[1] RHOA = (10∗∗(-(10∗∗((SLOPES∗TEMP)-NTRCPS))))

[2] RHOB = (10∗∗(-(10∗∗((SLOPES∗TEMP∗∗2)-NTRCPS))))

APPENDIX B. SURFACE RUNOFF AND SEDIMENT LOSS

Surface Runoff and Sediment Loss

B.1 Introduction

The objective of this appendix is to describe the models used to estimate surface runoff and sediment transport from the sludge management area. Surface runoff and sediment transport are two key mechanisms of pathogen removal from a sludge management area. Surface runoff is modeled with the Soil Conservation Service (SCS) procedure. Sediment transport is estimated with the Modified Universal Soil Loss Equation (MUSLE). Both the SCS method and MUSLE are event based models (as opposed to continuous simulation models) since each method is applied only to a single rainfall-runoff occurrence and neither accounts for changes in soil moisture that take place between rainfall events.

B.2 SCS Method for Surface Runoff

The Soil Conservation Service (1972) developed a method for estimating surface runoff from small watersheds. The procedure is simple and requires few input parameters all of which can be estimated from measurable characteristics of the watershed. The SCS method entails three steps:

(1) Find the excess rainfall hyetograph,
(2) Estimate the SCS unit hydrograph, and
(3) Compute the total outflow from the watershed.

Each step is discussed below. An example calculation is included to illustrate application of the SCS method to a sludge management area.

B.2.1 Excess Rainfall Hyetograph

Excess rainfall is that portion of the total rainfall which becomes direct runoff during a rainfall event. According to the SCS method, excess rainfall is computed from total rainfall in the following way

$$P_e = \frac{(P-0.2S)^2}{P+0.8S} \qquad \text{(B-1)}$$

where

P_e = excess rainfall in centimeters
P = total rainfall in centimeters and
S = potential maximum retention in centimeters.

Potential maximum retention S is related to a dimensionless curve number by

$$S = 2.54[(1000/CN)-10] \tag{B-2}$$

in which the curve number CN is a lumped measure of the soil and cover characteristics of the watershed. Table B.1 summarizes recommended values of the curve number for various combinations of soil groups and cover conditions. The curve number has a value between 0 and 100. When CN=0, there is no runoff and excess precipitation is zero; when CN=100, there are no abstractions (losses) and excess precipitation equals the total precipitation. Between these extremes, the curve number provides an empirical threshold for sorting total rainfall into abstractions or direct runoff. This is evident in Figure B.1 which presents solutions to equation (B-1) as a family of curves for selected CN values.

The results shown in Figure B.1, apply to normal antecedent moisture conditions, called AMC2. For dry conditions (AMC1) or wet conditions (AMC3), the curve number is adjusted in the following manner

$$CN1 = [4.2(CN2)]/[10-.058(CN2)] \tag{B-3}$$

$$CN3 = [23(CN2)]/[10+0.13(CN2)] \tag{B-4}$$

where $CN2$ is the curve number for normal conditions obtained from Table B.1. Criteria to judge the prevailing AMC are summarized in Table B.2.

It is assumed in this study that the distribution of total rainfall during the course of the storm can be described with a triangular hyetograph. This approach has been found to provide a reasonable approximation of many storm patterns (Yen and Chow, 1977 and 1980) and, furthermore, it renders the

Table B.1
Runoff Curve Numbers for Hydrologic Soil-Cover Complexes.

(Based on normal antecedent moisture conditions, AMC2).

Soil Cover			Hydrologic Soil Group**			
Land Use	Treatment or Practice	Hydrologic Condition	A	B	C	D
Fallow	Straight row	----	77	86	91	94
Row Crops	Straight row	poor	72	81	88	91
	Straight row	good	67	78	85	89
	Contoured	poor	70	79	84	88
	Contoured	good	65	75	82	86
	Contoured & terraced	poor	66	74	80	82
	Contoured & terraced	good	62	71	78	81
Small grain	Straight row	poor	65	76	84	88
	Straight row	good	63	75	83	87
	Contoured	poor	63	74	82	85
	Contoured	good	61	73	81	84
	Contoured & terraced	poor	61	72	79	82
	Contoured & terraced	good	59	70	78	81
Seeded legumes or rotation meadow	Straight row	poor	66	77	85	89
	Straight row	good	58	72	81	85
	Contoured	poor	64	75	83	85
	Contoured	good	55	69	78	83
	Contoured & terraced	poor	63	73	80	83
	Contoured & terraced	good	51	67	76	80
Pasture or Range	Untreated	poor	68	79	86	89
	Untreated	fair	49	69	79	84
	Untreated	good	39	61	74	80
	Contoured	poor	47	67	81	88
	Contoured	fair	25	59	75	83
	Contoured	good	6	35	70	79

(continued)

Table B.1
Runoff Curve Numbers for Hydrologic Soil-Cover Complexes (cont'd).

(Based on normal antecedent moisture conditions, AMC2).

Soil Cover			Hydrologic Soil Group**			
Land Use	Treatment or Practice	Hydrologic Condition	A	B	C	D
Meadow	Untreated	good	30	58	71	78
Woods	Untreated	poor	45	66	77	83
		fair	36	60	73	79
		good	25	55	70	77
Farmsteads	Untreated	----	59	74	82	86
Roads	Dirt	----	72	82	87	89
	Hard surface	----	74	84	90	92

From: Soil Conservation Service (1972)

**Notes:

A = Low runoff potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well drained sands or gravels. These soils have a high rate of water transmission.

B = Moderately low runoff potential. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C = Moderately high runoff potential. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. These soils have a slow rate of water transmission.

D = High runoff potential. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

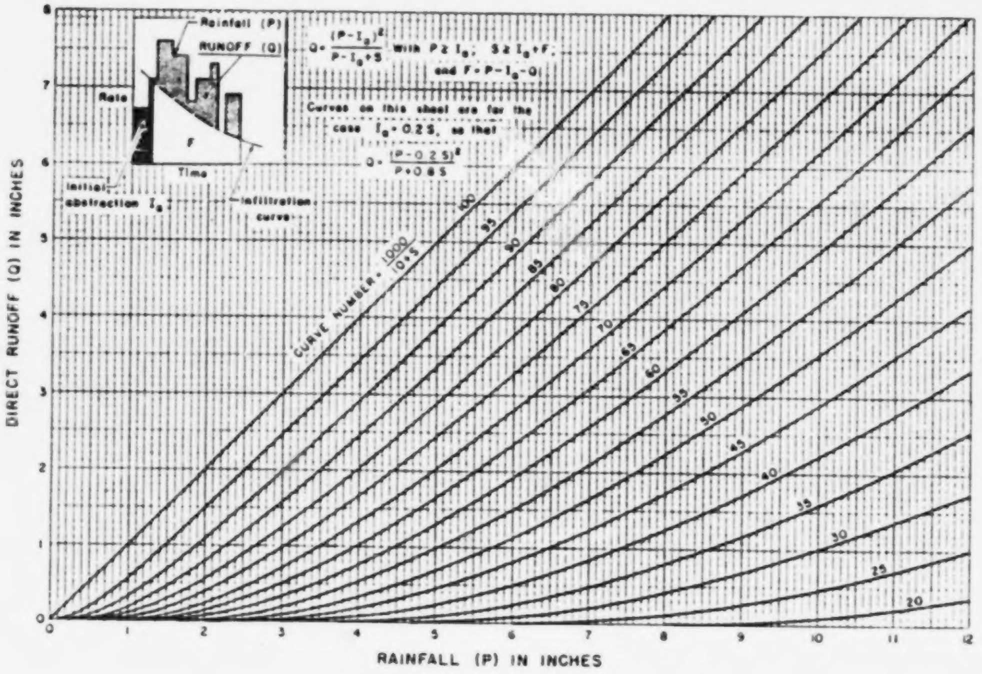


Figure B.1 Solution of the SCS runoff equation (from SCS, 1972).

Table B.2
SCS antecedent moisture conditions.

AMC Group	Total 5-day antecedent rainfall (cm)	
	Dormant Season	Growing Season
1	< 1.3	< 3.5
2	1.3 to 2.8	3.5 to 5.3
3	> 2.8	> 5.3

Adapted from: Soil Conservation Service (1972)

subsequent rainfall-runoff analysis quite tractable. Once total precipitation P and storm duration T are specified, maximum rainfall intensity is given by

$$h_{max} = 2P/T \qquad \text{(B-5)}$$

The rise time of the rainfall hyetograph or time at which the maximum intensity occurs is

$$t_r = \rho T \qquad \text{(B-6)}$$

where ρ is a dimensionless parameter called the "storm advancement coefficient" and is defined as the ratio of the time before the peak intensity to the total duration of the storm. When $\rho=0.5$, the maximum rainfall intensity occurs at the middle of the storm. If $\rho<0.5$, then the peak occurs before the midpoint and if $\rho>0.5$, then the peak intensity occurs after the midpoint of the storm. Typical values for the storm advancement coefficient are listed in Table B.3. The recession time of the triangular rainfall hyetograph is given as the difference between the total duration and the rise time or

$$t_s = T-t_r \qquad \text{(B-7)}$$

Table B.3
Storm advancement coefficient.

Location	ρ value
Baltimore, Maryland	0.399
Chicago, Illinois	0.294 to 0.375
Cincinnati, Ohio	0.325
Cleveland, Ohio	0.375
Philadelphia, Pennsylvania	0.414
Ontario, Canada	0.480
Gauhati, India	0.416

From: Chow, Maidment and Mays (1988)

To find the corresponding excess rainfall hyetograph, it is first necessary to find the rainfall abstractions. Provided that moisture is not limiting, it is assumed that rainfall abstractions occur at a constant potential rate during the storm. The potential loss rate ϕ, known as the "phi index", is found using

$$\phi = (1-\alpha)h_{max} \tag{B-8}$$

where h_{max} is defined in equation (B-5) and α is a dimensionless scaling parameter computed as

$$\alpha = (P_e/P)^{0.5} \tag{B-9}$$

in which the excess precipitation P_e is found using equation (B-1). Then the excess rainfall hyetograph i(t) is computed from the total rainfall h(t) using

$$\begin{aligned} i(t) &= h(t) - \phi \qquad \text{if } h(t) > \phi \\ i(t) &= 0 \qquad\qquad\quad \text{otherwise} \end{aligned} \tag{B-10}$$

A comparison of the excess rainfall hyetograph (ERH) and the total rainfall hyetograph (TRH) is presented in Figure B.2. The TRH begins at time zero, increases linearly to a peak intensity of h_{max} at time t_r, then decreases

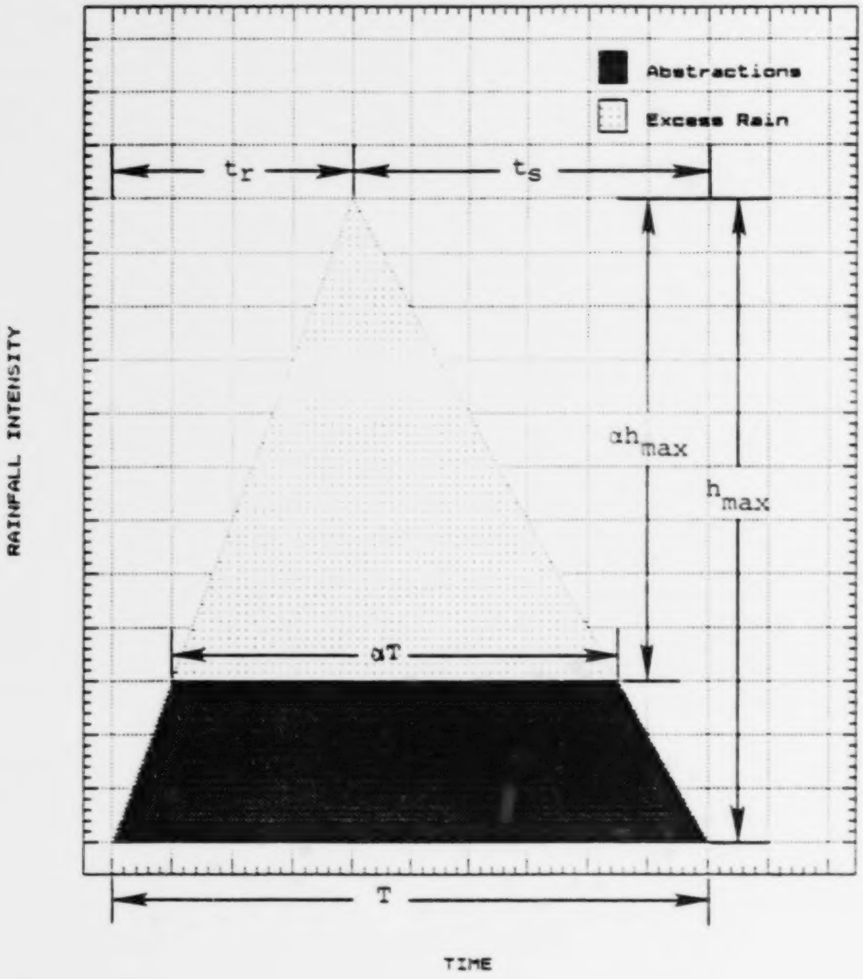

Abstractions
Excess Rain
t_r
t_s
αh_{max}
h_{max}
αT
T
RAINFALL INTENSITY
TIME

Figure B.2 Triangular hyetograph showing abstractions and excess rainfall.

in a linear manner and returns to zero at time T. The ERH begins at time $(1-\alpha)t_r$, increases linearly to a peak intensity of $i_{max} = \alpha h_{max}$ at time t_r, then decreases in a linear manner returning to zero at time $T-(1-\alpha)t_s$. As shown in Figure B.2, the timing of the ERH peak intensity coincides with the peak intensity of the TRH. However, the magnitudes of the peak and the duration of the ERH are less than the peak and duration of the TRH by a factor α as defined above in equation (B-9).

The ERH plotted in Figure B.2 gives the instantaneous intensity of the excess rainfall during the course of the storm. In application, it is most useful to visualize the excess rainfall as a sequence of discrete pulses during which the rate of rainfall is constant. This is accomplished by dividing the ERH into intervals of duration Δt and then computing an equivalent uniform intensity as the average rainfall intensity over the time interval. The resulting sequence of nonzero pulses, $i_e(m)$ for $m=1,2,\ldots,M$, where M is the total number of excess rainfall pulses, defines a discretized triangular ERH as shown in Figure B.3. Note that the corresponding incremental depth of excess precipitation occurring during the mth time interval is found using

$$\Delta P_e(m) = i_e(m)\Delta t \qquad \text{(B-11)}$$

and, to satisfy the mass balance, the sum of the incremental depths must recover the excess precipitation computed with equation (B-1) for the entire storm or

$$P_e = \sum_{m=1}^{M} \Delta P_e(m) \qquad \text{(B-12)}$$

The discretized ERH shown in Figure B.3 defines the precipitation loading to the sludge management area. The next step of the surface water analysis is to determine the runoff response of the sludge management area resulting from a unit loading of rainfall lasting for a given duration.

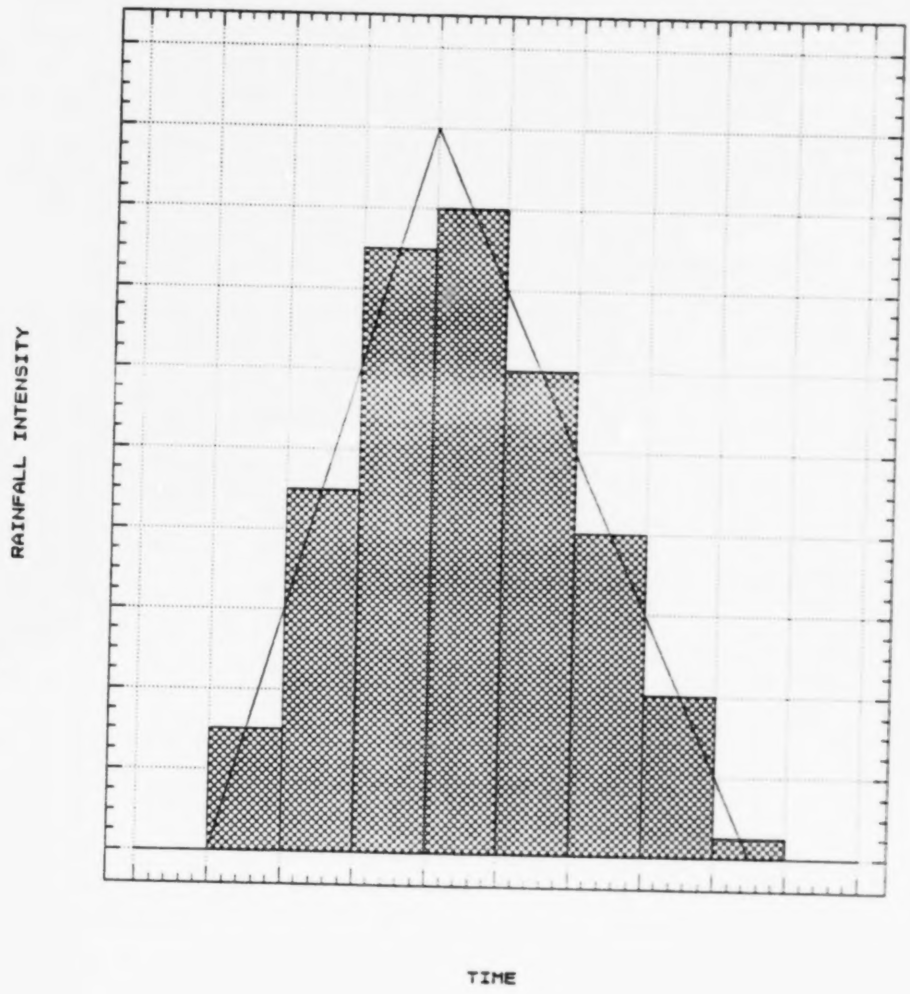


Figure B.3 Discretized excess rainfall hyetograph.

B.2.2 SCS Unit Hydrograph

The unit hydrograph is the direct runoff hydrograph resulting from one unit (e.g., one centimeter) of excess rainfall generated uniformly over the drainage area at a constant rate for some specified duration. The SCS unit hydrograph shown in Figure B.4 is triangular and, hence, completely defined with three parameters: (1) q_p--peak flow per centimeter of excess rainfall, (2) T_p--time to peak and (3) T_b--time of base.

The basin lag time, t_l, of the SCS unit hydrograph is defined as the difference in time between the centroid of the precipitation pulse and the peak of the unit hydrograph. As demonstrated with the nomograph in Figure B.5, basin lag time can be estimated from readily measured watershed characteristics. Given the basin lag time, the key parameters of the SCS unit hydrograph are computed as follows:

$$q_p = 2.08A/T_p \qquad (m^3/s{\cdot}cm) \qquad \text{(B-13)}$$

$$T_p = 0.5\Delta t + t_l \qquad \text{(hours)} \qquad \text{(B-14)}$$

$$T_b = 2.67T_p \qquad \text{(hours)} \qquad \text{(B-15)}$$

In equation (B-13), A is the drainage area of the watershed in square kilometers and in equation (B-14), Δt is the duration in hours of the pulse of excess precipitation. As a rule of thumb, reasonable results are usually obtained when the duration of the excess rainfall pulse is taken as about 20% of the estimated basin lag time, or $\Delta t \approx 0.20t_l$.

B.2.3 Total Discharge Hydrograph

The total hydrograph is found by successively applying the discrete pulses of the excess rainfall hyetograph to the ordinates of the SCS unit hydrograph and then summing the resulting discharges corresponding to a particular time index. The mechanics of this procedure are illustrated in Figure B.6. The

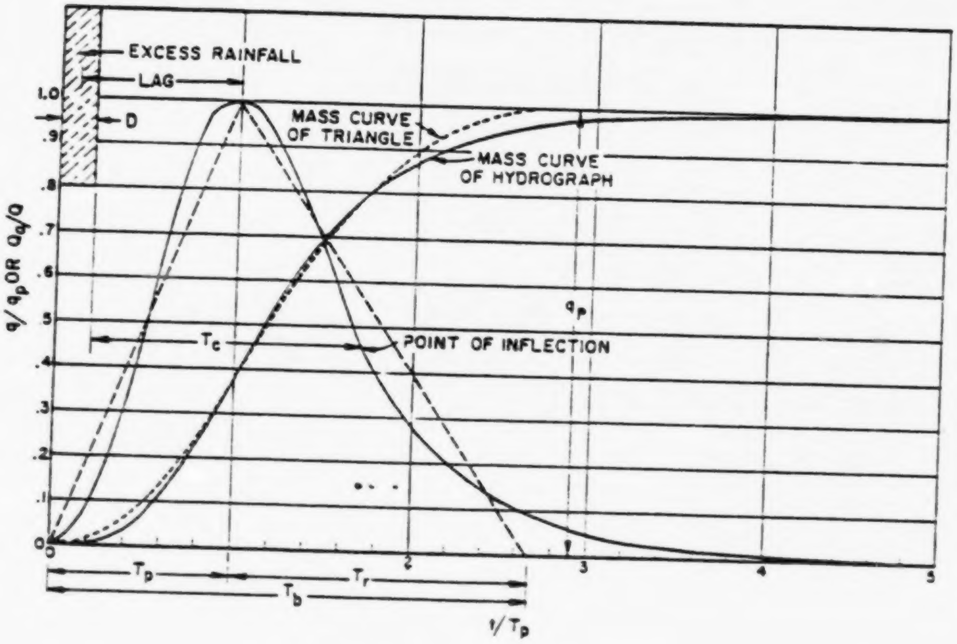


Figure B.4 SCS triangular unit hydrograph (from SCS, 1972).

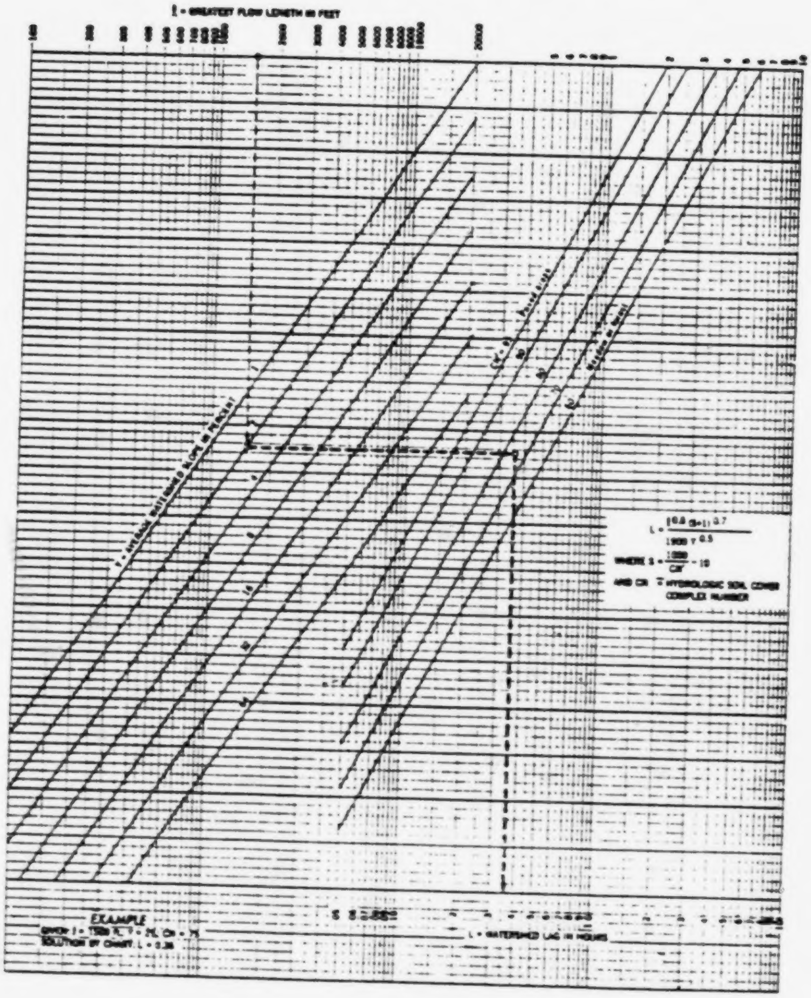


Figure B.5 Curve number method for estimating lag time (from SCS, 1972).

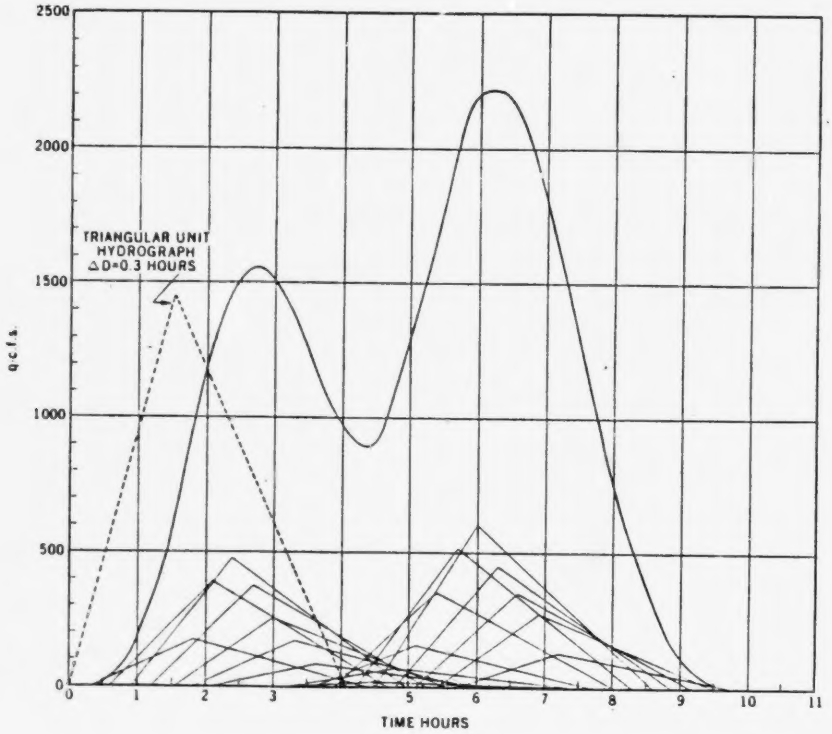


Figure B.6 Composite discharge hydrograph (from SCS, 1972).

mathematics of the procedure are represented with the discrete time convolution equation for a linear system

$$Q(n) = \sum_{m=1}^{n \leq M} \Delta P_e(m) U(n-m+1) \qquad \text{for } n=1,2,\ldots,N \qquad \text{(B-16)}$$

in which $\Delta P_e(m)$ is the incremental depth of excess precipitation given in equation (B-11) and $U(.)$ is the ordinate of the SCS unit hydrograph defined according to one of the following three conditions

$$U(k) = \beta q_p \qquad \text{if } 0 \leq \beta \leq 1 \qquad \text{(B-17a)}$$

$$U(k) = [(2.67-\beta)/(2.67-1)] q_p \qquad \text{if } 1 \leq \beta \leq 2.67 \qquad \text{(B-17b)}$$

$$U(k) = 0 \qquad \text{otherwise} \qquad \text{(B-17c)}$$

where q_p is given in equation (B-13), $\beta=(k\Delta t)/T_p$ is a dimensionless parameter, the time to peak T_p is given in equation (B-14), and Δt is the duration of the excess precipitation pulse. In equations (B-16) and (B-17), the indices $k=1,2,\ldots,K$, $m=1,2,\ldots,M$ and $n=1,2,\ldots,N$ are counters for the unit hydrograph ordinates, nonzero pulses of the ERH, and values of the discharge hydrograph, respectively. The upper limits of these indices satisfy $N=K+M-1$.

B.3 Modified Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) is an empirical relation to predict average soil loss from sheet and rill erosion from a catchment. With USLE, soil loss is expressed as the product of six factors that affect upland erosion by water (Wischmeier and Smith, 1978; Foster, 1982b):

$$E = RKLSCP \qquad \text{(B-18)}$$

in which

E = soil loss (erosion) over some time period in kg/m^2,
R = rainfall erosivity factor in EI units (N/hr),
K = soil erodibility factor in (kg·hr)/(m^2·N).

L = slope length factor (dimensionless),
S = slope steepness factor (dimensionless),
C = cover management factor (dimensionless) and,
P = supporting practices factor (dimensionless).

The USLE is intended to estimate average soil loss over an extended period of time, usually taken as one year. Williams (1975) suggested that USLE could be used to estimate sediment loss from a catchment during a single storm event by rewriting equation (B-18) as

$$E = R'KLSCP \tag{B-19}$$

Equation (B-19) is known as the "Modified" Universal Soil Loss Equation (MUSLE). Sediment yield is now given in megagrams for the total catchment (instead of kg/m^2) provided K has units of Mg·hr/ha·N. The chief difference between equations (B-18) and (B-19) is that the rainfall erosivity factor R has been replaced with a runoff energy factor R' defined as

$$R' = a(Vq_p)^b \tag{B-20}$$

in which a and b are regression coefficients, V is the volume of runoff in m^3, and q_p is the peak discharge in m^3/s.

The values of the coefficients a and b in equation (B-20) vary depending on location. Default values for a and b are usually taken as 9.05 and 0.56, respectively, for the SI system of units. The value of the MUSLE R' factor then can be estimated using the peak flow and runoff volume of the SCS hydrograph described in the previous section. The peak flow of the hydrograph is obtained by inspection while the runoff volume can be estimated from

$$V = \Delta t \sum_{n=1}^{N} Q(n) \tag{B-21}$$

in which Q(n) is the discharge given by equation (B-16) and Δt is the (constant) duration of the excess precipitation pulse.

The soil erodibility factor K is a measure of the average soil loss per unit area from the catchment. It has been found that K is a function of five soil characteristics: (1) percent silt, (2) percent coarse sand, (3) percent organic matter, (4) soil structure, and (5) soil permeability. A nomograph for computing soil erodibility from these five soil properties is shown in Figure B.7.

The slope length factor L is a relationship showing how soil erosion increases with slope length. It is given by

$$L = (\lambda/22.1)^m \qquad \text{(B-22)}$$

in which λ = actual slope length of the catchment in meters and m is an exponent whose value is summarized in Table B.4.

The slope steepness factor S measures the effect of land slope on the ability of rainfall and runoff to detach and transport sediment. It is given by

$$S = 65.41 \sin^2\theta + 4.56 \sin\theta + 0.065 \qquad \text{(B-23)}$$

where θ is the gradient of the land surface measured as a slope angle.

Table B.4
Exponent m for the slope length factor L in MUSLE.

Value of m	Catchment Slope, s
0.30	$s < 3\%$
0.40	$3\% \le s \le 5\%$
0.50	$s > 5\%$

From: Simons, Li & Associates (1982)

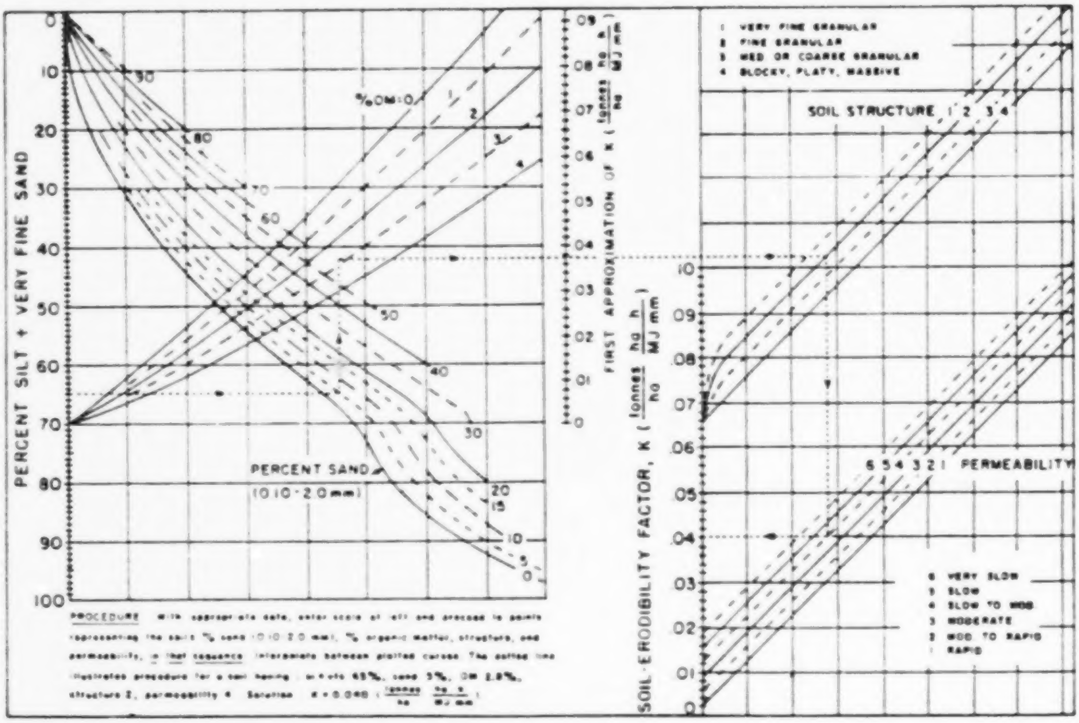


Figure B.7 Soil erodibility nomograph (from Foster, 1982a).

The cover management factor C represents the ratio of soil quantities eroded from land that is cropped under specified conditions to that which is eroded from clean tilled fallow under identical slope and rainfall conditions. It has been found that the cover management factor can be expressed as the product of three terms

$$C = C_1 C_2 C_3 \tag{B-24}$$

which account for the effect of ground canopy cover (C_1), ground mulch cover (C_2) and residual effects of previous land uses (C_3). These factors can be estimated from the graphs shown in Figure B.8.

The supporting practices factor P accounts for the effect of conservation measures such as contouring, strip cropping, and terracing on soil erosion. For straight row farming, P has a value of one. Other estimates of the supporting practices factor P can be obtained from Table B.5.

Table B.5
Supporting Practice Factor P in MUSLE.

Land Slope	Contouring	Strip Cropping Alternate Meadows	Strip Cropping Alternate Crops
1.1 to 2.0%	0.60	0.30	0.45
2.1 to 7.0%	0.50	0.25	0.40
7.1 to 12.0%	0.60	0.30	0.45
12.1 to 18.0%	0.80	0.40	0.60
18.1 to 24.0%	0.90	0.45	0.70

From: American Society of Civil Engineers (1977)

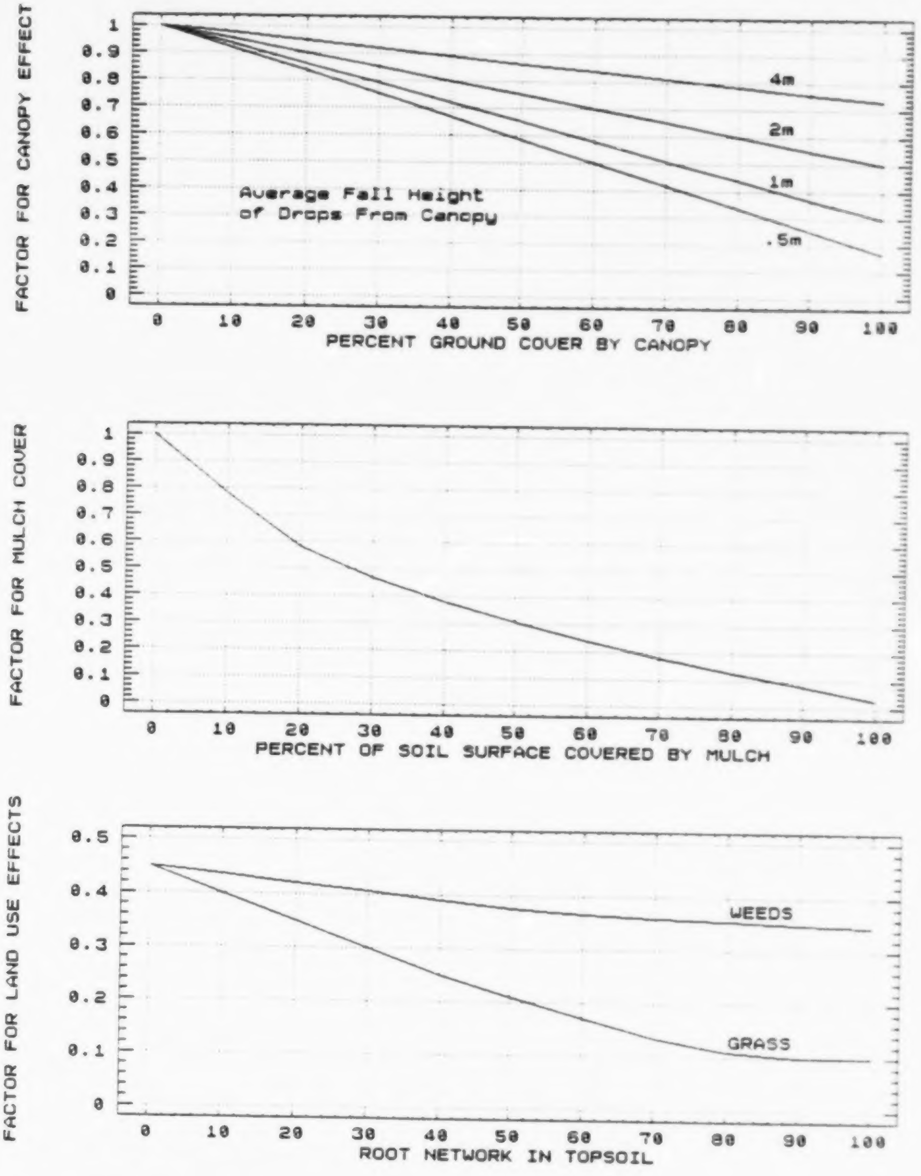


Figure B.8 Diagrams for estimating cover management factor.

Given sediment yield E, the corresponding depth of soil erosion D in centimeters taken as a uniform loss over the entire watershed is given by

$$D = E/(100\gamma A) \qquad \text{(B-25)}$$

in which E is sediment yield in Mg from equation (B-19), A is watershed area in ha, γ is the unit weight of soil in Mg/m^3 and 100 is a conversion factor.

B.4 Pathogen Transport

Following is a brief description of the simple algorithm for transport of pathogens from the sludge management area.

B.4.1 Pathogen Removal in Surface Runoff

Prior to the occurrence of a rainfall event at the sludge management area, there is a pathogen population of size N on site. These pathogens are assumed to be adsorbed on particles in the soil matrix and uniformly distributed throughout the top ten centimeters of the soil horizon. During the course of a storm, it is assumed that some fraction Θ of the pathogen population becomes suspended in the total rainfall measured at the land surface.

Pathogens which enter suspension may be transported from the site by two mechanisms: (1) over the land surface via rainfall runoff or (2) through the soil matrix via rainfall infiltration. Assuming that pathogens in suspension are uniformly mixed and close to the land surface, the maximum percentage of suspended pathogens that will be carried off-site in runoff can be approximated by the ratio of excess rainfall (runoff) to total rainfall. It follows, therefore, that a conservative estimate of the total number of pathogens suspended in surface runoff N_r that can be transported off-site during a rainfall event is

$$N_r = \Theta\alpha^2 N \qquad \text{(B-26)}$$

where α is defined in equation (B-9) and Θ and N are defined above.

B.4.2 Pathogen Removal in Sediment Yield

Even if a pathogen is not suspended in the surface runoff, it may be removed from the sludge management area while adsorbed to a soil particle that is detached and carried off-site by surface runoff. Assuming that pathogens which remain adsorbed are uniformly distributed over the upper ten centimeters of the soil profile, then the total number of pathogens adsorbed on sediment N_s that will be carried off-site during a rainfall event can be approximated with

$$\begin{aligned} N_s &= (D/10)(1-\Theta)N \qquad \text{for } D \leq 10 \text{ cm} \\ N_s &= (1-\Theta)N \qquad \text{for } D > 10 \text{ cm} \end{aligned} \qquad \text{(B-27)}$$

where D is given in equation (B-25) and the quantity $1-\Theta$ is the percentage of pathogens adsorbed to sediment. Solutions for equations (B-26) and (B-27) are shown in Figure 9.

The primary advantage of the expressions given in equations (B-26) and (B-27) is their ease of application. However, there is little guidance available for selecting values of the suspension fraction Θ which it seems should be related to storm intensity and duration, time between storms, nature and number of pathogens and the type and composition of the soil. In addition, it should be emphasized that such a simple approach has other more serious shortcomings including:

(1) The method generates a single number to represent the dynamic response of very complex transport phenomenon.

(2) The method provides no estimate of temporal or spatial changes in pathogen concentrations during the course of the storm.

(3) The method is not sensitive to the distribution of pathogens in the soil profile at the start of the storm.

(4) The method does not account for other natural biochemical and physical processes (e.g., pathogen growth and decay during storm) which could have a significant impact on the transport mechanism.

(5) The method is not rigorously linked to water and sediment transport processes.

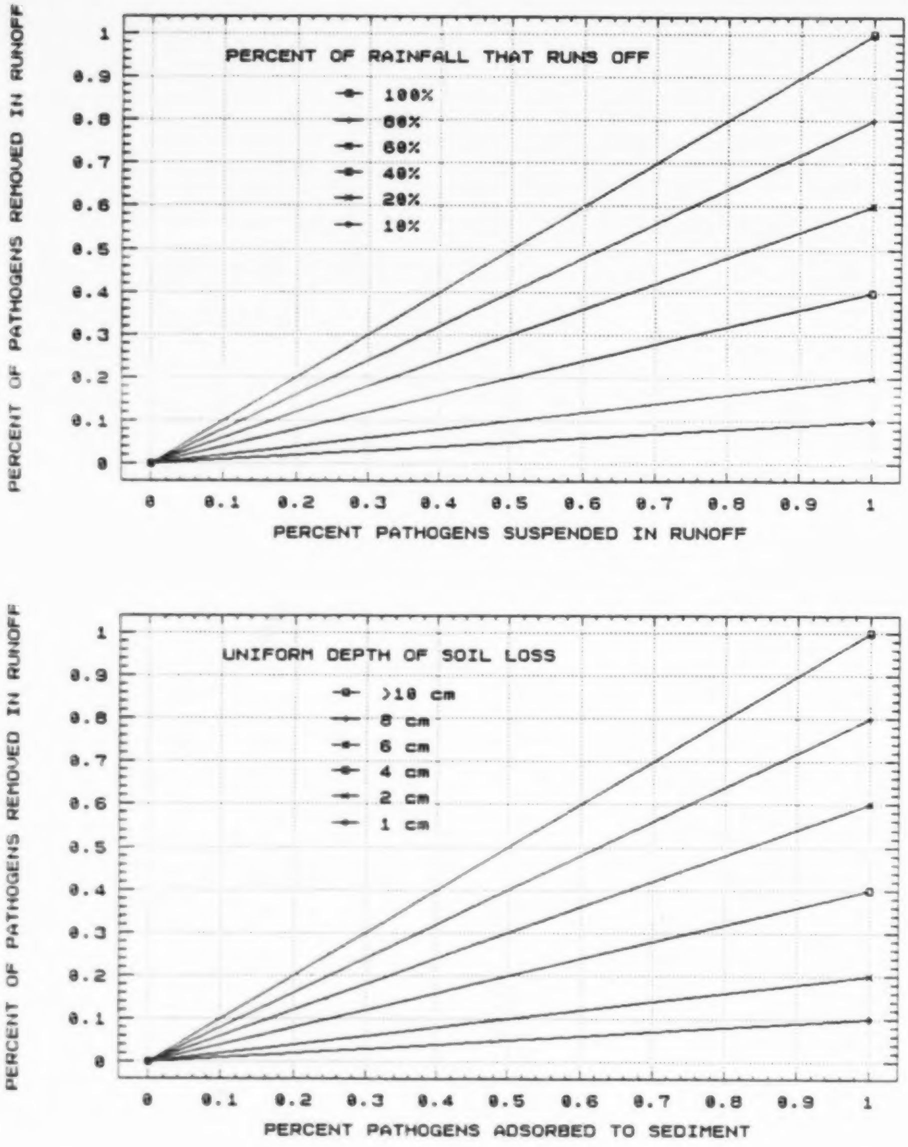


Figure B.9 Percent pathogens removed in runoff and on sediment.

B.5 Example Calculation

Input parameters for an example storm are summarized in Table B.6.

Table B.6
Input parameters for example showing SCS method for surface runoff and MUSLE for sediment transport.

Parameter	Rainfall Event
Duration, T	1 hour
Total Precipitation, P	8.13 cm
Watershed Area, A	70 ha
Basin lag time, t_l	0.50 hours
Watershed Curve Number, CN	80
Antecedent Moisture Conditions	AMC2
Storm Advancement Coefficient, ρ	0.40
USLE K factor	0.40 Mg·hr/ha·N
USLE L factor	3.00
USLE S factor	0.25
USLE C factor	0.40
USLE P factor	1.00
Pathogen suspension factor, Θ	0.30

With normal antecedent moisture conditions, the curve number remains at 80. The potential maximum retention is found from equation (B-2)

$$S = 2.54[(1000/80) - 10] = 6.35 \text{ cm}$$

Putting this result into equation (B-1) gives the excess precipitation expected at the sludge management area

$$P_e = \frac{[8.13 - (0.2)(6.35)]^2}{8.13 + (0.8)(6.35)} = 3.56 \text{ cm}$$

Using this value and information from Table B.6 in equations (B-5) through (B-10), the total rainfall hyetograph (TRH) and the excess rainfall hyetograph (ERH) are computed. Results are summarized in Tables B.7 and B.8 and are plotted in the top half of Figure B.10.

Table B.7
Parameters for example storm.

Parameter	TRH	ERH
duration, T	1.00 hours	0.66 hours
start time	0.00 hours	0.14 hours
rise time, t_r	0.40 hours	0.26 hours
peak time	0.40 hours	0.40 hours
recession time	0.60 hours	0.40 hours
total rainfall, P	8.13 cm	3.56 cm
peak intensity	16.26 cm/hr	10.76 cm/hr
total abstractions	4.57 cm	0.00 cm
potential loss rate, ϕ	5.50 cm/hr	0.00 cm/hr

Note: based on α=0.662 from equation (B-9).

Table B.8
Instantaneous rainfall hyetographs for example storm.

Time Since Start of TRH (hours)	Instantaneous TRH Intensity h(t), cm/hr	Time Since Start of ERH (hours)	Instantaneous ERH Intensity i(t), cm/hr
0.000	0.00	-----	0.00
0.050	2.03	-----	0.00
0.100	4.06	-----	0.00
0.136	5.50	0.000	0.00
0.150	6.10	0.014	0.60
0.200	8.13	0.064	2.63
0.250	10.16	0.114	4.66
0.300	12.19	0.164	6.69
0.350	14.22	0.214	8.72
0.400	16.26	0.264	10.76
0.450	14.91	0.314	9.41
0.500	13.54	0.364	8.04
0.550	12.19	0.414	6.69
0.600	10.85	0.464	5.35
0.650	9.47	0.514	3.97
0.700	8.13	0.564	2.63
0.750	6.78	0.614	1.28
0.797	5.50	0.661	0.00
0.800	5.41	0.664	0.00
0.850	4.06	0.714	0.00
0.900	2.72	0.764	0.00
0.950	1.35	0.814	0.00
1.000	0.00	0.864	0.00

To discretize the ERH, rainfall pulses of duration $\Delta t=0.10$ hour (20% of the given basin lag time) are used. Accordingly, the number of ERH pulses is $M=0.66$ hour/0.10 hour giving 6.6 say 7 pulses.

These pulses of excess precipitation are shown in the lower half of Figure B.10 which offers the following interpretation of the example storm. Within the one hour storm, which produces 8.13 centimeters of total rainfall, there is a continuous period lasting 0.66 hours during which 3.56 centimeters of excess precipitation (runoff) are generated. This excess rainfall is modeled as seven consecutive but discrete pulses of rainfall each having a duration of $\Delta t=0.10$ hours. The excess rainfall pulses are tabulated in Table B.9.

Table B.9
Discrete excess rainfall hyetograph for example storm.

Pulse No. m	Time Since Start of ERH (hours)	Instantaneous ERH Intensity $i(t)$, cm/hr	Average Intensity (cm/hr)	Incremental Excess Precipitation $\Delta P_e(m)$, cm
	0.00	0.000		
1			2.033	0.203
	0.10	4.065		
2			6.098	0.610
	0.20	8.131		
3			9.741*	0.974
	0.30	9.803		
4			8.448	0.845
	0.40	7.093		
5			5.738	0.574
	0.50	4.383		
6			3.028	0.303
	0.60	1.672		
7			0.516**	0.052
	0.70	0.000		
			Total: $\Sigma \Delta P_e(m) = P_e =$	3.56

Note: *The average intensity for pulse #3 computed as the weighted sum of average intensities before and after the peak at 0.26 hours of the ERH.

**The average intensity for pulse #7 computed as the weighted sum of average intensities before and after the end of the ERH at 0.66 hours.

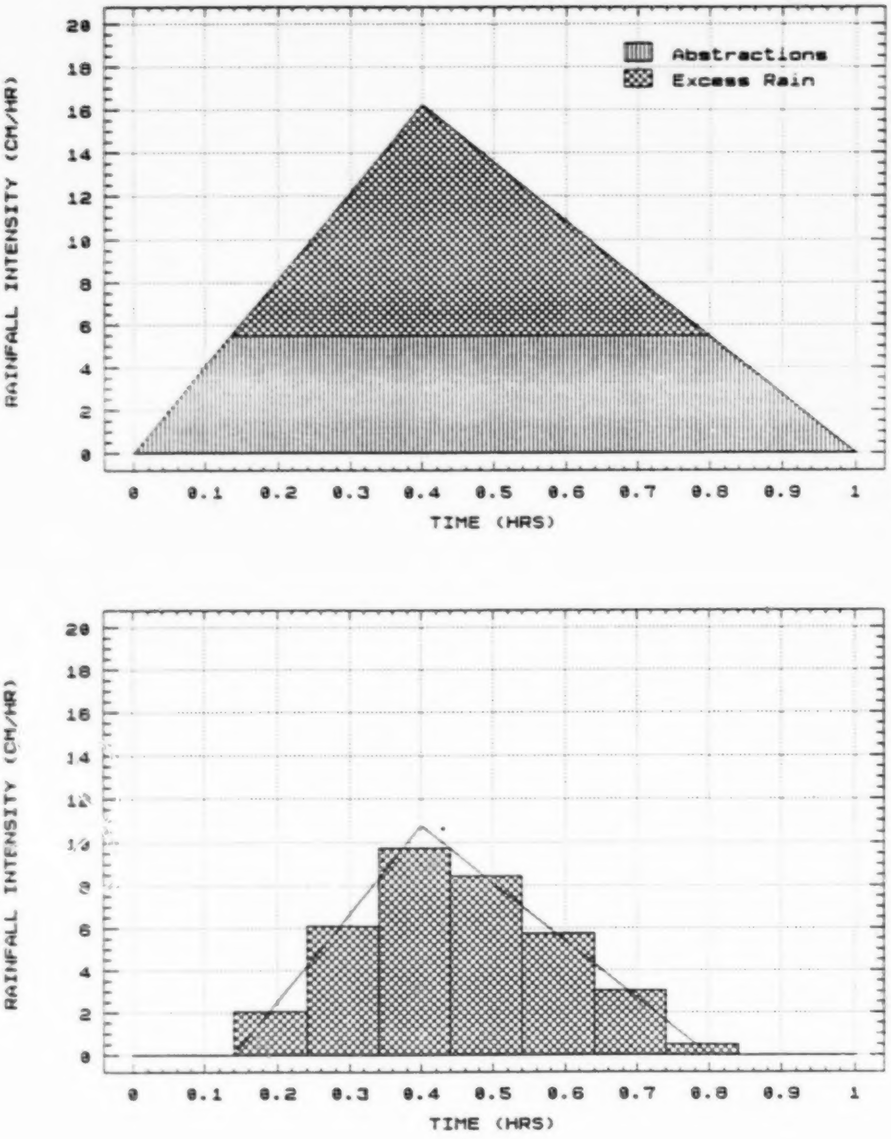


Figure B.10 Total and excess rainfall hyetographs for example storm.

Equations (B-13), (B-14) and (B-15) are used to compute the three parameters of the SCS unit hydrograph,

$$T_p = 0.50(0.10 \text{ hr}) + 0.50 \text{ hr} = 0.55 \text{ hr}$$

$$T_b = 2.67(0.55 \text{ hr}) = 1.47 \text{ hr}$$

$$q_p = 2.08(0.70)/0.55 = 2.65 \text{ m}^3/\text{s}$$

With these results, the discrete time ordinates of the triangular SCS unit hydrograph are computed with equation (B-17) and summarized in Table B.10. The derived unit hydrograph given in Table B.10 and the estimated excess rainfall hyetograph given in Table B.9 are combined using the discrete time convolution formula given in equation (B-16) to compute the total direct runoff from the site. Results are given in Table B.11 and also are plotted in Figure B.11.

Table B.10
SCS unit hydrograph for example storm.

Index, k	β	Time, hours	Unit Hydrograph, U(k) in m^3/s·cm	
0	0.00	0.00	0.00	equation (17a)
1	0.18	0.10	0.48	"
2	0.36	0.20	0.95	"
3	0.55	0.30	1.46	"
4	0.73	0.40	1.93	"
5	0.91	0.50	2.41	"
6	1.09	0.60	2.50	equation (17b)
7	1.27	0.70	2.22	"
8	1.45	0.80	1.93	"
9	1.64	0.90	1.63	"
10	1.82	1.00	1.35	"
11	2.00	1.10	1.06	"
12	2.18	1.20	0.78	"
13	2.36	1.30	0.49	"
14	2.55	1.40	0.19	"
15	2.73	1.50	0.00	equation (17c)

Note: $\beta = (k\Delta t)/T_p$ where Δt=0.10 hour and T_p=0.55 hour.

Table B.11
Discharge hydrograph for example storm.

Time Index n	Unit Hydrograph Ordinates (m^3/s·cm)	Excess Precipitation (cm)							Runoff Q(n) (m^3/s)
		0.203	0.610	0.974	0.845	0.574	0.303	0.052	
1	0.48	0.10							0.10
2	0.95	0.19	0.29						0.49
3	1.46	0.30	0.58	0.47					1.34
4	1.93	0.39	0.89	0.93	0.41				2.61
5	2.41	0.49	1.18	1.42	0.80	0.28			4.17
6	2.50	0.51	1.47	1.88	1.23	0.55	0.15		5.78
7	2.22	0.45	1.53	2.35	1.63	0.84	0.29	0.02	7.10
8	1.93	0.39	1.35	2.44	2.04	1.11	0.44	0.05	7.82
9	1.63	0.33	1.18	2.16	2.11	1.38	0.58	0.08	7.83
10	1.35	0.27	0.99	1.88	1.88	1.44	0.73	0.10	7.29
11	1.06	0.22	0.82	1.59	1.63	1.27	0.76	0.13	6.41
12	0.78	0.16	0.65	1.31	1.38	1.11	0.67	0.13	5.41
13	0.49	0.10	0.48	1.03	1.14	0.94	0.58	0.12	4.38
14	0.19	0.04	0.30	0.76	0.90	0.77	0.49	0.10	3.36
15	0.00		0.12	0.48	0.66	0.61	0.41	0.08	2.35
16	0.00			0.19	0.41	0.45	0.32	0.07	1.44
17	0.00				0.16	0.28	0.24	0.06	0.73
18	0.00					0.11	0.15	0.04	0.30
19	0.00						0.06	0.03	0.08
20	0.00							0.01	0.01
21	0.00								0.00
								Total: ΣQ(n) =	**69.01**

Notes: (1) 1 m^3/s = 35.31 cfs

(2) M = 7 (number of excess precipitation pulses)
K = 14 (number of ordinates of unit hydrograph)
N = M+K-1 = 20 nonzero values of the discharge hydrograph.

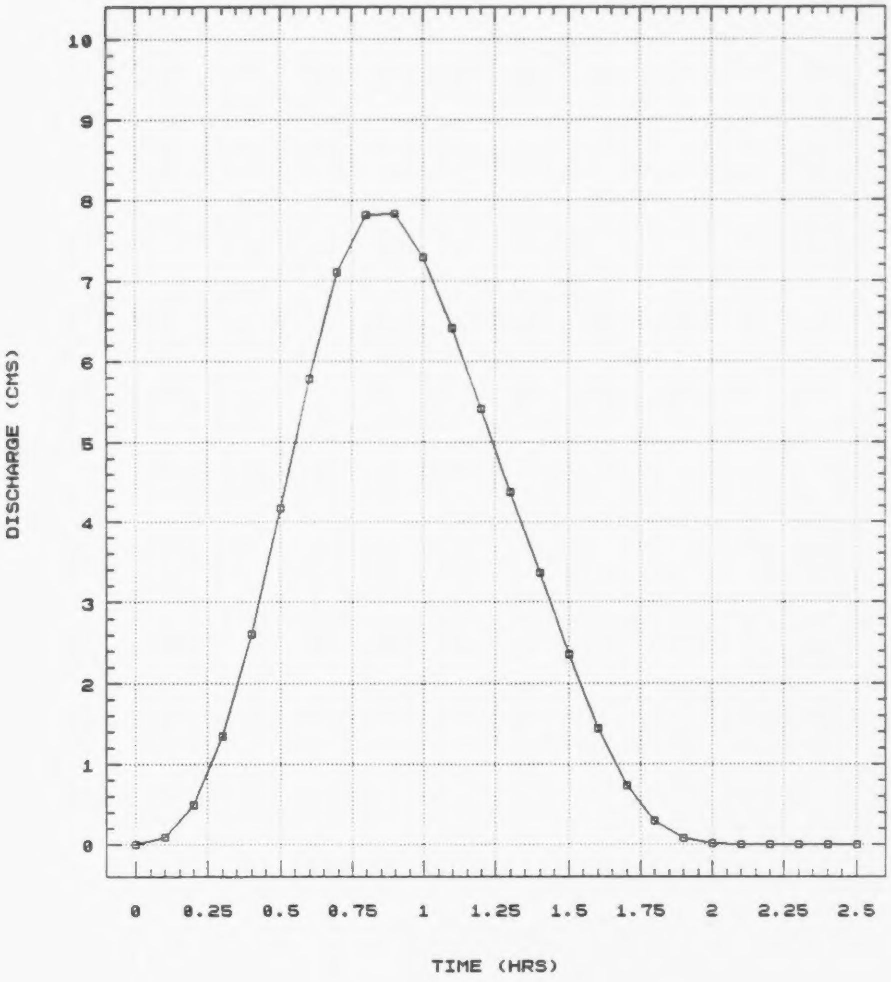


Figure B.11 Discharge hydrograph for example storm.

At this point, MUSLE can be used to estimate sediment loss expected from the sludge management area during the given one hour storm. The total volume of runoff is found using equation (B-21) with $\Delta t=0.10$ hr and $\Sigma Q(n)=69.01$ m^3/s

$$V = (.10\ hr)(3600\ sec/hr)(69.01\ m^3/s) = 24{,}844\ m^3$$

The maximum discharge q_p occurs at time index $n=9$ and is read directly from Table B.11, $q_p = 7.83$ m^3/sec. Then the MUSLE runoff energy factor is found using equation (B-20)

$$R' = 9.05(24{,}844 \times 7.83)^{0.56} = 8{,}290$$

The sediment yield from the sludge management area is estimated by putting the computed value of R' and the values of the five remaining MUSLE factors K,L,S,C, and P given in Table B.6 into equation (B-19)

$$E = (8{,}290)(0.40)(3.0)(0.25)(0.40)(1.0) = 995\ Mg$$

Assuming that the unit weight of soil is 1.6 Mg/m^3, the uniform soil erosion from the 70 ha site is found with equation (B-25)

$$D = 995/[(100)(1.6)(70)] = 0.09\ cm$$

Finally, with a pathogen suspension fraction of $\Theta=30\%$, the percentage of pathogens carried off-site are found with equations (B-26) and (B-27)

$N_r/N = (0.30)(0.44) = 13.2\%$ (pathogens transported in runoff)

$N_s/N = (0.09/10)(0.70) = 0.63\%$ (pathogens transported on sediment)

B.6 References

American Society of Civil Engineers (1977) *Sedimentation Engineering*, edited by Vanoni, V.A., ASCE Manual No. 54, New York.

Chow, V.T., D.R. Maidment and L.W. Mays (1988) *Applied Hydrology*, McGraw-Hill Book Company, New York.

Foster, G.R. (1982a) "Relation of USLE Factors to Erosion on Rangeland" in Proceedings of Workshop held in Tucson, Arizona on Estimating Erosion and Sediment Yield on Rangelands, ARM-W-26, March 7-9, 1981, Available from ARS Western Region, U.S. Department of Agriculture, Oakland, California.

Foster, G.R. (1982b) "Modeling the Erosion Process", in Hydrologic Modeling of Small Watersheds, Edited by C.T. Haan, H.P. Johnson, and D.L. Brakensiek, ASAE Monograph No. 5, St. Joseph, Michigan.

Simons, Li and Associates (1982) *Engineering Analysis of Fluvial Systems*, SLA, Fort Collins, Colorado.

Soil Conservation Service (1972) *National Fngineering Handbook*, Section 4, Hydrology, U.S. Department of Agriculture, Washington, D.C.

Williams, J.R. (1975) "Sediment-Yield Prediction with Universal Equation using Runoff Energy Factor", in Present and Prospective Technology for Predicting Sediment Yields and Sources, ARS-40, U.S. Department of Agriculture--Agricultural Research Service, pp. 244-252.

Wischmeier, W.H. and D.D. Smith (1978) "Predicting rainfall erosion losses--a guide to conservation planning", US Department of Agriculture, Agriculture Handbook No. 537, US Government Printing Office, Washington, D.C.

Yen, B.C. and V.T. Chow (1977) "Feasibility Study on Research of Local Design Storms", FHWA Report No. RD-78-65, US Department of Transportation, Washington, DC.

Yen, B.C. and V.T. Chow (1980) "Design Hyetographs for Small Drainage Structures", Proceedings ASCE, Journal of the Hydraulics Division, 106(HY6):1055-1076.